Chapter 4

Sampling Adults with Non-attractant Traps

Adults of haematophagous Diptera, especially mosquitoes, are usually caught by using human or animal baits or in light or carbon dioxide traps. No single trapping technique will attract all species present in an area. For example, certain species are not attracted to light and very few ornithophagic species will be caught at human bait. But even when several species are caught by the same method it is most unlikely that they will be equally attracted, consequently their populations will not be equally sampled. This, however, is not always a serious limitation. In many virus isolation studies, for example, it does not matter whether mosquito vectors are sampled with the same efficiency, so long as sufficiently large numbers are caught. Sometimes, however, especially in ecological investigations, more representative samples of mosquito populations are needed. Because of the virtual impossibility of finding an attractant trap that will sample equally all species, it is best to use non-attractant traps. A disadvantage of these, however, is that because they catch mosquitoes only in their immediate area the numbers obtained are small unless mosquito populations are large.

Whereas most attractant traps are heavily biased in favour of collecting unfed females orientated to host-feeding, non-attractant traps give more representative samples of both sexes and the different physiological conditions and age groups. However, it is important to remember that all the traps discussed in this chapter sample the aerial population, hence the numbers caught depends not only on population density but also on the flight activities of the individuals. Unfed females in fact usually comprise the greatest element of the catch, mainly because they are normally the most active. A non-attractant trap is unlikely to be completely free from sampling bias although every effort is made to minimise this. For example, the physical presence of a trap may promote visual responses, causing mosquitoes to be either attracted or repelled by it; similarly the hum of the motor in suction traps may influence the numbers caught. Despite these limitations aerial populations of insects can usually be more efficiently sampled, and with less bias, than most aquatic or terrestrial invertebrate populations. Suction traps probably give the most reliable estimates of both relative and absolute population size.

For a better understanding of the total mosquito populations in an area the non-active resting populations should also be sampled (see preceding chapter).

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Malaise traps

This trap which was originally invented by Dr René Malaise (1937) has been modified and simplified many times and used to catch a variety of insects. Breeland & Pickard (1965), however, appear to have been the first to specifically report on its usefulness in catching mosquitoes. They used a modified Malaise trap designed by Townes (1962). The original paper should be consulted for a detailed step by step construction of the trap, but the four basic parts are as follows: (1) a wooden frame about 76 in square and 50 in tall held in position with guy ropes and within which the trap is supported (this is not an essential component, and is not needed if the trap can be suspended between conveniently placed trees etc.); (2) a lower part of the trap which consists of four baffles set at right angles to each other and made from two pieces of 102 × 42 in, *black* mosquito netting; (3) a pyramid of *white* netting divided by four white baffles fixed over the framework and lower baffles; (4) a collecting jar consisting of a curved metal cone leading to a transparent plastic funnel, underneath which is a killing bottle, which is fitted over the opening in the apex of the pyramid (Fig. 4.1*a,b*). Insects flying into the trap are prevented from escaping by the lower baffles and fly upwards into the lightest part of the trap, and eventually pass into the killing jar. Pinger *et al.* (1975) used Townes-type (1962) Malaise traps in the USA and over about 4·5 months, a period when mosquitoes were active, trapped 8604 mosquitoes, of which 36% were *Aedes vexans*, 13% were *Aedes trivittatus* and another 13% were *Culiseta inornata*, while *Culex pipiens, Culex restuans* and *Culex salinarius* formed 31% of the catch, and just 3% were *Culex tarsalis*. In other studies Pinger & Rowley (1975) caught 385 blood-fed mosquitoes in Malaise traps, as against only 215 in CDC light-traps supplemented with dry ice.

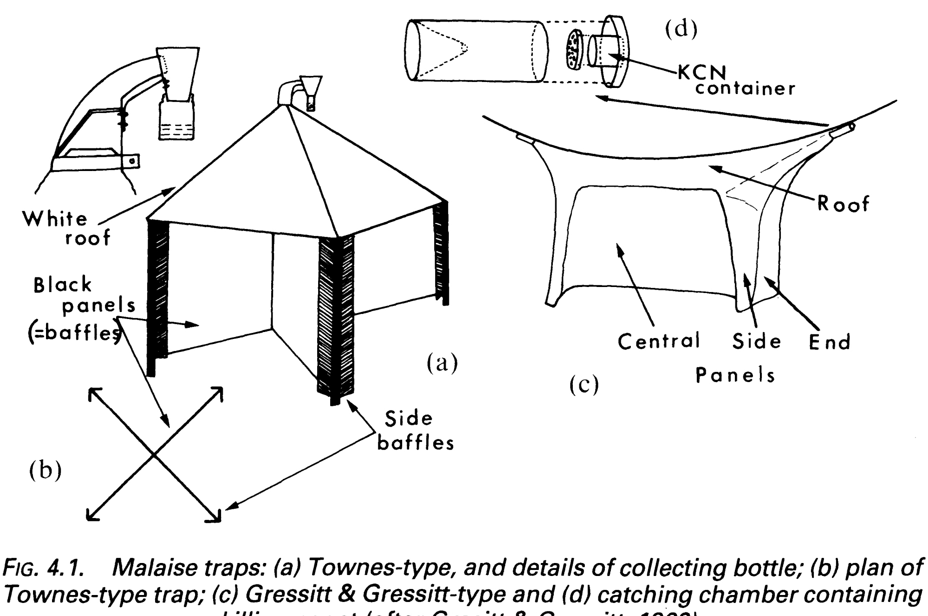

FIG. 4.1. Malaise traps: (a) Townes-type, and details of collecting bottle; (b) plan of Townes-type trap; (c) Gressitt & Gressitt-type and (d) catching chamber containing killing agent (after Gresitt & Gressitt, 1962).

Marston (1965) described a useful trap made by suspending the net part of a Malaise trap within a framework of tubular aluminium having telescopic legs, such as used in tents. Apart from being very light it is claimed that the trap can be erected in about 10 min. More insects appeared to be caught when the cage was made of 'Visqueen' polystyrene than when 'Saran' cloth was used, but unfortunately this type of polystyrene deteriorates rapidly in sunlight.

Breeland & Pickard (1965) found that, of the 29 mosquito species they collected in Tennessee, 27 were collected in Townes-type Malaise traps compared with 19 in light-traps, and about 3½ times as many females as males were caught. They considered that these traps gave more representative samples of mosquito populations than light-traps. In Texas, Easton *et al.* (1968) used a trap similar to that designed by Townes except that the framework was constructed of aluminium and not wood, and they also concluded that a Malaise trap could be a useful survey tool for mosquitoes.

Both Gressitt & Gressitt (1962) and Butler (1965) used much simpler traps. Of the three rather similar nets described by Gressitt & Gressitt (1962) for use as Malaise traps the one that should prove most suitable for catching mosquitoes is as follows. The net is made from black nylon organdie and consists of a central median panel 7 m long and 3·6 m high, with two end panels 1·8 m wide and set at right angles (Fig. 4.1*c*). The roof is made to slope downwards on either side of the central panel. Panels 20 cm wide are sewn to the edges of the roof and the side panels and slant inwards to help retain the catch. At the two ends of the central panel the nylon netting of the roof and the end panels is extended to form a cone of netting leading to a plastic cylindrical collecting tube. A straight length of rope is run along under the centre of the roof adjacent to the central panel, to emerge through the conical extensions. The two plastic collecting tubes are fixed to this rope which is slanted upwards and tied to a tree. Each collecting tube is 22 × 10 cm with an inverted funnel at the entrance. The opposite end of the tube is removable and contains a small container with a perforated removable lid. A killing agent, such as cyanide wrapped in cotton wool or absorbent paper, is placed in the small tube (Fig. 4.1*d*). Two thinner pieces of rope support the two outer edges of the roof panel, and are tied to a tree or staked to the ground some distance from the trap. Rope is used to tie down the four bottom corners of the side panels and the two corners of the median panel. Finally, a 30-cm high double strip of heavy black cotton poplin is sewn on to the lower edge of the median panel to help weight it down.

Butler's trap (1965) is even simpler. It is made from a mosquito bed-net by cutting out one of the longer side panels, but leaving a 1-ft deep strip along the top edge. For greater strength it is advisable, though not essential, to sew a 10-in square piece of cloth into the middle of the roof panel before a hole is cut out from it and a metal cylinder (coffee tin with both ends removed), is inserted. A transparent plastic bag is tied by an elastic band to the top end of the cylinder. A killing agent can be placed at the bottom of the plastic bag. Two light pieces of wood (dowels, bamboo canes etc.) are inserted across the inside of the two short sides of the roof panel to hold the net open. A long loop of nylon cord is attached to each of the projecting ends of the wooden supports. A piece of wire or string is passed under each nylon loop and attached in the middle to the top of the cylinder and its end secured to a tree. This arrangement results in pulling the centre of the roof panel upwards about 18 in so that a funnel-shaped roof is formed that leads to the collecting bag.

In Canada Hudson (1981) used three variations of the Malaise traps of Hocking (1970). There was a large one which was fixed (intercepting 10 m^2 of air), a medium-sized cone (2 m^2), and a small one (0·5 m^2) with a wind vane so that it moved with the wind. These traps were inspected once or twice a day.

Roos (1957) used a trap divided vertically into two equal parts, each with its own collecting bottle. Thus insects from two opposite directions were caught and retained separately. He positioned his traps over streams to study the upstream migration of aquatic insects. Pruess & Pruess (1966) also used a directional trap but had a separate collecting bottle for each of the four sides which faced the cardinal points of the compass. A total of 104 mosquitoes were caught.

Although they can be cheap, easy to make and operate, and require the minimum of attention, Malaise traps have been relatively little used for collecting mosquitoes. It is often assumed that provided shadows are not cast over their entrance they give unbiased collections of insects (Breeland & Pickard 1965; Graham, 1969; Gunstream & Chew, 1967), but it seems likely that at least some insects, including mosquitoes, will either be attracted to, or repelled by, Malaise traps. Townes (1962) for example recognised that different trap designs might affect the relative proportions of different species of insects caught in the trap. Roberts (1970) concluded that tabanids did not just blunder at random into Malaise traps but responded to both trap colour and its light reflectance. For example, he showed that old Malaise traps of the Townes design having saran screening that had darkened with age caught significantly fewer tabanids than traps with new paler screens (Roberts, 1975). Vision plays a very important part in host location by tabanids, so it is not surprising that they can respond to the presence of Malaise traps. Roberts (1978) also discusses the effects that modifications, such as introduction of internal horizontal baffles and addition of carbon dioxide, has on the tabanids collected in Malaise traps, while Darling & Packer (1988) studied the effect of trap design, mesh size and location of Malaise traps in Canada for sampling Hymenoptera. Vision is not generally so important in mosquitoes for host seeking, consequently Malaise traps may give more representative population samples, but this needs to be critically evaluated. On Ellesmere Island in Canada, Corbet & Danks (1973) found that site position can markedly effect the catch of mosquitoes in Malaise traps. They concluded that although the traps were unlikely to have given reliable data on the relative numbers of *Aedes nigripes* and *Aedes impiger*, they were nevertheless useful in providing phenological information on the emergence, periods of flight activity and reproduction in these two species. Graham (1969) also used Malaise traps in Canada. He reasoned that if mosquitoes rest on vegetation until they become activated by the presence of suitable baits then 'not so many hungry mosquitoes' will be caught in Malaise traps, with the result that populations will not be adequately sampled. Two issues are being confused. In any area mosquito populations will comprise both flying and non-flying adults, and Malaise traps, like suction traps and others employing an attractant, only sample the aerial population.

In California, Gunstream & Chew (1967) compared the mosquitoes collected in Townes-type Malaise traps and CDC light-traps using a 0·15-A, radio light. The same seven species of mosquitoes were collected by both traps. The relative proportions of *Psorophora confinnis, Culex tarsalis, Aedes dorsalis* and *Aedes vexans* varied greatly according to the trapping method. For example, the ratio of the total female catch of these four species in Malaise traps was about 24·7:67·3:2·5:1, whereas in the light-trap the ratios were 1322:86·0:58·0:1·0. In all species a higher proportion of blood-fed females were caught in the Malaise traps, and it was concluded that this trap probably gave more realistic relative measures of population size of the different species than light-traps.

Malaise traps are normally used at ground level but they can also be suspended at various heights, and can be used to catch both day and also night-flying mosquitoes.

Roberts (1976) provides photographs of several types of Malaise traps, as well as the plexiglas trap (Schreck *et al.*, 1970), the canopy trap (Catts, 1970) and a Manning trap (Hansens *et al.*, 1971), in an evaluation of their attractiveness to tabanids.

Malaise traps have not been widely used for catching mosquitoes in the tropics, but Bailly-Choumara (1973) reported they were of little value in Morocco.

Window trap

In Iceland Jónsson *et al.* (1986) used, very successfully, a new type of window trap for catching large numbers of chironomids and *Simulium vittatum*. The trap, which might be useful for catching mosquitoes, consists of a 16 × 20-cm perspex box, 16 cm high and divided in the middle by a 20 × 36-cm sheet of perspex (window). The two compartments of the box are filled to a depth of about 12 cm with 4–6% formalin containing a few drops of detergent; in winter ethylene glycol can be added to prevent freezing. One or two holes drilled in one side of the box at 12 cm and covered with fine netting prevent the trap overflowing after heavy rain. Traps are mounted on aluminium poles. Flying insects on hitting the transparent vertical plastic window fall into the formalin.

Ramp traps

Gillies (1969) devised a directional trap, variously called the ramp, flight or intervention trap. These traps allowed the entry of mosquitoes from only one direction, but unlike the traps of Nielsen (1960) or Provost (1960) they were not used to investigate the exodus of mosquitoes from breeding sites but to study the flight direction of hungry unfed females. The traps were used at, or just above, ground level. Each trap is composed of two separate parts, a ramp unit and a detachable collecting cage. The ramp consists of a wooden frame 6 ft long and 3 ft wide, covered with plastic or glass fibre netting and fixed by upright supports at an angle of 135°. Two triangular sections make up the ramp frame. Initially each side section has the two equal sides 4 ft 6 in long, but the upper inner corners are cut off to leave an upper side about 4 ft 2 in in length. These two

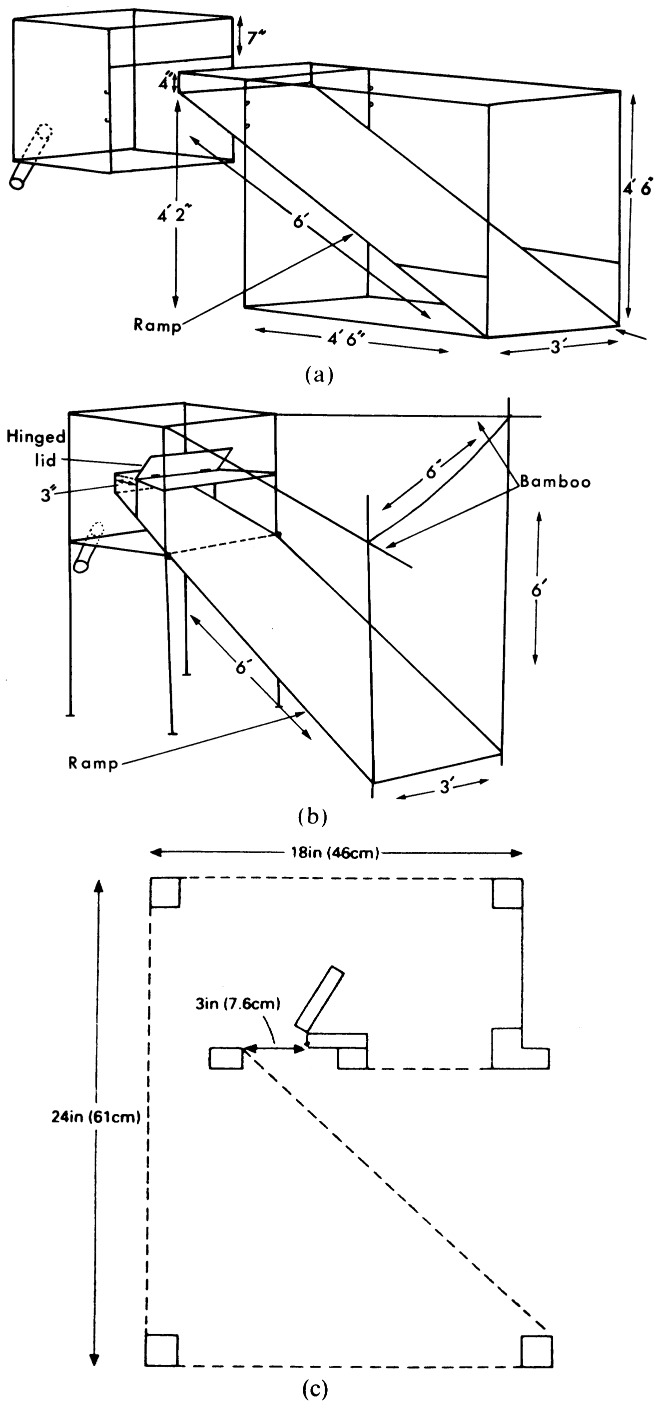

FIG. 4.2. Ramp traps: (a) original model (Gillies, 1969); (b) modified model (Gillies & Wilkes, 1972); (c) entrance of modified model (after Gillies & Wilkes, 1972).

sections are mounted on either side of the ramp platform and a 4 ft 2-in long, 3-ft wide roof rests horizontally across them (Fig. 4.2*a*). When these side frames are fitted together, a 4-in gap, through which mosquitoes pass into the collecting cage, is left between the top edge of the ramp and the inner edge of the roof. The framework of the entire ramp unit is covered with netting. The collecting cage which is 3 ft 5 in wide, 1 ft 5 in deep and 2 ft high, fits tightly against the vertical supports of the ramp. A horizontal strut fixed some 7 in from the top of the cage enables it to rest across the roof of the ramp. The section of the front wall that fits over the ramp is covered with wood, while the rest of the cage is covered with netting. Gillies (1969) found that the section of wooden frame of the ramp unit that projected into the cage had to be tapered so that when the two were fitted together a clearance was left between the sides of the cage and the netting on either side of the entry slit. Without this modification some mosquitoes rested in inaccessible parts of the cage and were difficult to collect. Any gaps can be filled in with cotton wool or foam rubber. When the trap is not in use a removable mesh screen is placed over the ramp entrance to prevent various insects entering the trap. There is nothing critical about the dimensions of the trap; all that is required is a suitably inclined ramp that will guide mosquitoes into a collecting cage. Gillies (1969) pointed out that on moonlit nights traps would be more readily seen than on moonless nights, and since some mosquitoes might be either attracted or repelled by them, catches on these nights might differ. He also observed that a ramp trap could reduce wind speed on the leeward side by about 50%.

These traps were successfully used in West Africa to study the orientation of several mosquito species, including *Anopheles melas, Culex thalassius, Culex tritaeniorhynchus* and the *Culex decens* group, to carbon dioxide and animal baits (calf and man) (Gillies & Wilkes, 1969, 1970).

In a further study on the range of attraction of mosquitoes (mainly *Anopheles ziemanni, Mansonia africana, Mansonia uniformis, Culex thalassius, Culex decens* group and *Aedes* spp.) to both carbon dioxide and bait animals a modified trap was devised (Gillies & Wilkes, 1972). The most important change in design was the separation of the ramp from the collecting cage. This cage is 2 ft high, 3 ft wide, 1 ft 6 in deep and covered with plastic netting and is mounted on a 4-ft high stand. A 3-in entry slit with a hinged wooden lid is made in the cage as shown in Fig.4.2*b,c*). The ramp unit consists of a sloping rectangular frame covered with wide-mesh nylon netting which is hooked on to the top of the cage stand. Its bottom edge rests on the ground 6 ft in front of the stand supporting the collecting cage. The tops of two 6-ft high vertical stakes inserted into the ground on either side of the bottom edge of the ramp are connected to the cage by horizontal bamboo canes. The funnel-shaped framework that results from this construction is covered with wide-mesh, double weave cotton netting. This netting was chosen in preference to ordinary mosquito netting as it presents less wind resistance. The funnel entrance to the trap is about 6 ft high and a little less than 6 ft wide. In general these traps caught larger numbers of mosquitoes than the older type, presumably due, at least in part, to the larger cross-sectional area of the ramp entrance. There was, however, little increase in the catch of certain *Anopheles* species.

When the traps were not in use insects were prevented from entering them by simply closing the slit entrance with the hinged lid. The traps were prone to damage by strong winds. To reduce this the horizontal bamboo canes were loosely attached to the vertical supports, and the netting loosely tied to the vertical bamboo canes inserted lightly into the ground. Consequently, in the face of strong winds the funnel entrance part of the trap collapsed but the rest of the trap was left intact.

Snow & Boreham (1973) used these ramp traps to study the mosquitoes attracted to pigeons and ducks which were placed in the space formed when two traps were placed back to back and the partition between them removed.

To study the vertical distribution of mosquitoes in a coastal area of The Gambia, Snow (1975) used the ramp traps of Gillies (1969) and Gillies & Wilkes (1972), and also 22·9-cm diameter 'Vent-Axia' suction traps. In five trials the ramp traps were set at heights of ground level–1·37 m, 0·69–2·06 m, 1·45–2·82 m, 2·13–3·51 m and 2·90–4·27 m, (Fig. 4.3), while in one series of experiments suction traps were placed at heights of 0·68, 2·13, 3·51 m, and in another at 0·91, 3·05, 6·10 and 9·15 m (Fig. 4.11). Most mosquitoes, including *Anopheles melas, Anopheles squamosus, Aedes pseudothoracis, Culex decens* group, *Culex tritaeniorhynchus,*

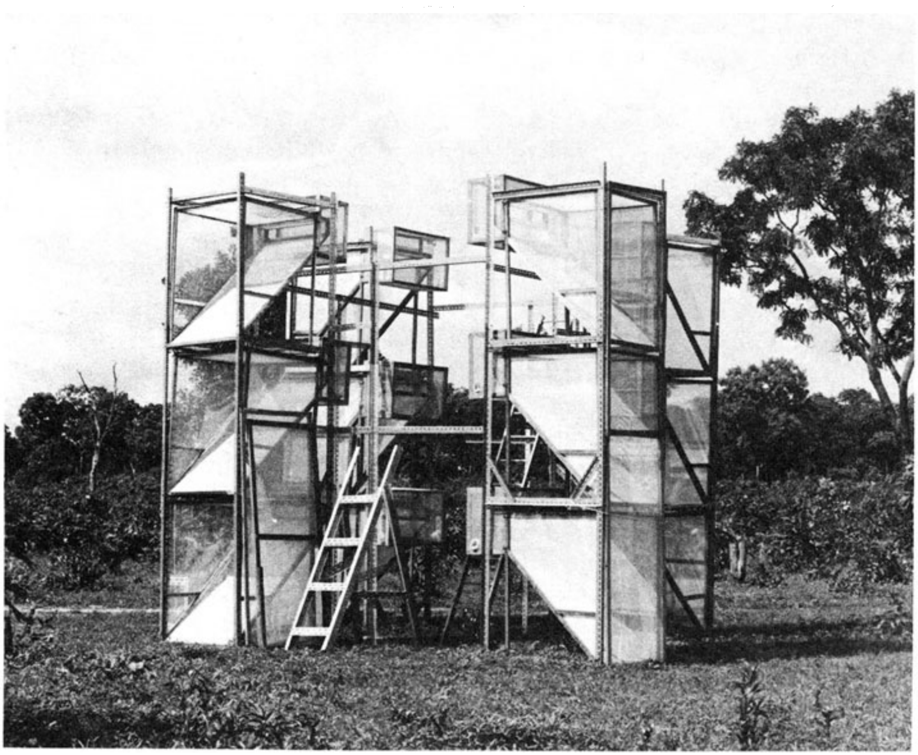

FIG. 4.3. Ramp traps at different levels operating in The Gambia (photograph courtesy of W. F. Snow).

Mansonia uniformis and *Mansonia africana* flew near the ground and were collected in the lower traps. Only the ornithophagic *Culex neavei* and *Culex weschei* were commonest in the higher traps.

There were larger catches of the *Culex decens* group and *Culex thalassius* in ramp traps on moonlit nights, probably because the traps were more visible on these nights. In contrast, catches in suction traps were not more numerous on moonlit nights, indicating that mosquitoes did not respond visually to these smaller traps. More *Anopheles melas* were caught in the suction traps than in the ramp traps, which they seemed to avoid. However, in later experiments, there were reduced catches of *Anopheles melas* in suction traps on moonlit nights, suggesting trap avoidance (Snow, 1982). Although ramp traps have been used in The Gambia to study mosquito flight levels and direction (Snow, 1975 1976, 1977; Snow & Wilkes, 1977), it seems that at least some species respond visually to the traps. For example, the *Culex decens* group and *Culex thalassius* were commonly caught in ramp traps, whereas *Anopheles melas* tended to avoid them. Ramp traps therefore may not give unbiased data. Suction traps were later preferred in studies on flight behaviour (Gillies & Wilkes, 1976, 1981; Snow, 1977).

Stationary nets

Fixed

Mosquitoes have occasionally been sampled by horizontal nets in which the opening, which is perpendicular to the ground, is permanently fixed in one direction. Nielsen (1960) used this type of net to catch windborne and migrating mosquitoes. Individuals not having a strong directional flight will not readily enter this type of net, or if they do, not many are retained. The trap consists of dark blue nylon netting made into the shape of a pyramid with a 2 × 2-m entrance narrowing at the opposite end to an 18-cm diameter opening. The four corners of the funnel-like net are fastened to curtain rings which can be slid up and down two vertical metal supporting rods. A 2½-m long, 18-cm diameter, cylindrical white nylon sleeve is fixed to the apex of the funnel and held out horizontally by tying the distal end to an upright support (Fig. 4.4*a*). Nielsen (1960) used a unit consisting of two nets mounted one above the other to study the dispersal of mosquitoes from their breeding places. Provost (1960) studying the dispersal of *Aedes taeniorhynchus* positioned a pair of such nets at approximately the four cardinal points of the compass facing inwards to the larval habitat. The lower net was centred about 6 ft above ground level and the upper one at about 15 ft. A marked downwind dispersal of mosquitoes was found.

Wind orientated

Although mosquitoes have been sometimes successfully caught in fixed stationary nets as described under the previous heading, nets used to sample aerial populations of insects are usually pivoted so that their openings always face into the wind (Broadbent, 1948; Davies, 1965; Farrow & Dowse, 1984; Freeman, 1945; Gorham 1946; Hardy & Milne, 1938; Johnson 1950*b*). Such nets are commonly referred to as 'tow nets', which can be misleading as they are not pulled or towed through the air. They do not sample mosquitoes flying in one particular

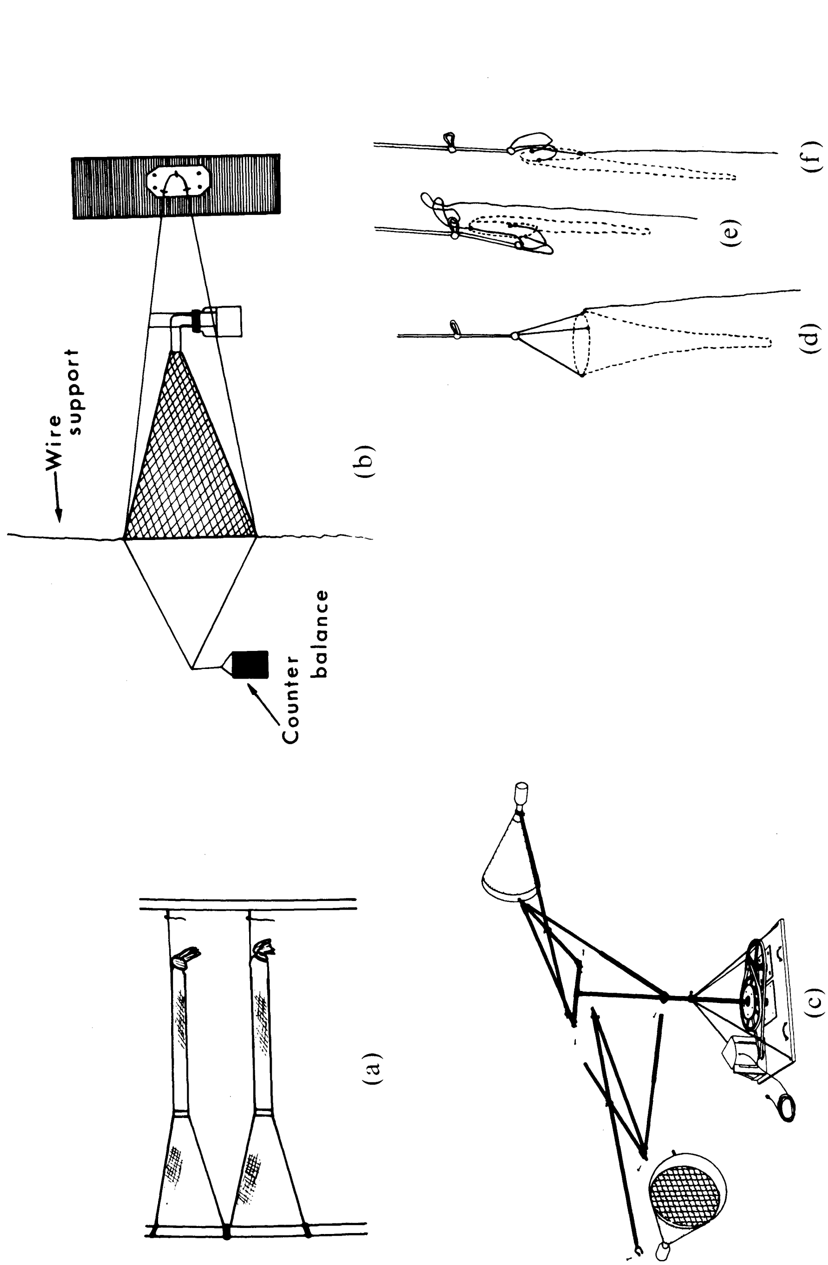

Fig. 4.4. *(a) Stationary net (from Nielsen, 1960); (b) wind orientated trap of J. B. Davies; (c) rotary trap (from Nicholls, 1960); (d–f) nets raised by balloons, (d) net open for catching on ascent; (e) net closed for ascending to catch height; (f) net closed for descending (after Nielsen & Greve, 1950).*

direction, but those flying with the wind. The volume of wind passing through any kind of stationary net is less than would pass through the same areas without a net. Holzapfel & Harrell (1968) measured the speed of the wind passing through net traps used on board ship by placing an anemometer in their entrances. At low speeds both fixed and wind-orientated nets may not be very efficient because mosquitoes may avoid entering them, but when wind speeds are in excess of the mosquito's flight speed, mosquitoes can be regarded as inanimate objects that are blown into the trap.

The numbers of mosquitoes caught in tow nets depends on the numbers of mosquitoes passing through unit area in unit time, such as m^2/s (i.e. flux or migration). Thus catches of insects at low density but travelling fast may be similar to catches of insects at higher density but travelling slower. With insects as small as mosquitoes their travelling speed can be equalised to wind speed. Consequently to compare aerial samples taken with different sized tow nets, in different wind speeds and for different durations, their densities can be computed as follows

$$\text{Density} = \frac{\text{catch/unit area}}{\text{volume of air sampled (m}^3\text{)}}$$

Radar provides instantaneous information on the numbers of insects in a volume of air about 10^7 m^3, whereas tow nets sample much less air, for example in moderate winds a net with a 1 m^3 opening samples about 5×10^4 m^3. However, although radar has been successfully employed to demonstrate insect migration it neither identifies the insects (Riley, 1979; Schaefer, 1976) nor can it usually detect insects smaller than about half the wavelength of the radar (i.e. about 15 mm for conventional 3-cm radar). Because of these and other problems associated with radar Farrow & Dowse (1984) used tow nets carried on kites in Australia for sampling insects from the upper air. However, 8·8-mm wavelength pulsed incoherent radar has recently been evaluated to study flights of insects weighing just 2 mg. Such radar can detect single planthoppers (body length 1·6 mm) at ranges of about 1·3 km (Riley, 1992). This type of radar clearly has potential in mosquito studies.

Numerous kite designs have been described (Pelham 1976) and many ready-made kites can be purchased (Jenkins, 1981). Farrow & Dowse (1984) made two versions of a double conyne kite (weighing 2·2 and 1·9 kg), and bought a parafoil kite weighing 850 g. Because aerial densities of insects can be low the cross-sectional area of the entrance of the tow nets was made as large (1 m^3) as the lifting power of the kite in light winds would allow, while the terylene 0·5-mm mesh net was made as light as possible (1050 g).

With winds of 10–20 km/hr or greater, kites were launched on 100–200 m of braided nylon line, using a winch or short tow by a vehicle driven as far as practical (2–5 km) at 5–30 km/hr. These kites were pulled to an operating height of 100–500 m. In light to moderate winds (15–50 km/h) the parafoil kite with a drogue gave the best lift, whereas with winds in excess of 50 km/h the smaller of the conyne kite with a drogue was best. A commercial radio-controlled system for model aircraft, using a tow-line trigger, enabled the tow nets to be opened when the kites were at the desired height and then closed. The aim was to get an airflow of 20–30 km/h through the net to retain the catch and prevent strongly flying insects from avoiding the tow nets. Tow nets were kept aloft for 1–3 hr, sometimes for 5 hr at night. In calmer weather, however, the kites remained airborne for just short periods (10–30 min). Nets could be raised and lowered independently of the kite, permitting the kite to remain aloft. A better arrangement, however, is to use helium-filled balloons to support nets which can remain in the air for much longer, and moreover can ascend greater heights.

For catching Ceratopogonidae in Jamaica, Davies (1965) used nylon nets with a 2-ft square opening suspended on a wire frame, and by the use of a wind vane ensured that they always pointed into the wind (Fig. 4.4*b*). The catching container was lined with sticky paper to retain the midges.

Taylor (1962*a*) described a useful isokinetic insect net, that is one with the inlet so designed that the airflow neither diverges nor converges at the edges of the inlet, the air-flow lines being straight. He concluded that such nets should sample small insects with an error of very much less than 10% in wind speeds above 8 mph, and that 100% efficiency is approached in winds of about 14 mph. Used in conjunction with an anemometer, isokinetic nets can be used to measure aerial densities, and would probably be useful in sampling aerial populations of mosquitoes in exposed situations, being especially valuable in places where there is no electricity to operate suction traps. Estimates can be made of absolute population size, and with this trap the appropriate formula is:

$$\text{No. mosquitoes}/10^6\ \text{ft}^3\ \text{of air} = \frac{\text{No. caught} \times 10^6}{1{\cdot}53 \times \text{outside wind run in ft}}$$

An estimate of aerial density (D) can be obtained from stationary nets from the following general formula devised by Johnson (1950*b*):

$$D = (T/(Ax)3600)K_x/100$$

where T = number of mosquitoes caught per hr, A = area of net opening in ft^2, x = wind speed in ft/s, K_x = percentage of air passing through the net at a wind speed of x ft/s. To use this formula the wind speed measured both outside and through the net must be obtained. The higher the wind speed then the greater the proportion that passes through the net.

Isard *et al.* (1990) described and illustrated an isokinetic net which was mounted on a helicopter to sample aphids at various heights, later the system was modified to allow discs to be electronically released by the pilot to segregate catches into 12 samples, in terms of elevation, location, time and volume of air sampled (Hollinger *et al.*, 1991).

Rotary traps

In North America during the 1940s through to about 1970, various designs of rotary traps, petrol driven or powered by electricity, were used by a few mosquito workers such as Chamberlin & Lawson (1945), Graham (1969), Horsfall (1942), Love & Smith (1957), Provost (1957) and Snow & Pickard (1957). More lately rotary traps have very rarely been used to catch mosquitoes. Taylor

& Palmer (1972) pointed out that rotary traps are usually more difficult to make than suction traps, and had no advantage over them. For these reasons no further space is devoted to these traps, apart from illustrating the design of Nicholls (1960) trap (Fig. 4.4*c*) to show the general configuration.

Moving traps

General considerations

These traps are of various shapes and sizes and can be pulled or towed through the air by aeroplanes (Glick, 1939; Glick & Noble, 1961; Gressitt *et al.*, 1961; Odinstov, 1960; Yoshimoto *et al.*, 1962*a*), by ships (Holzapfel & Harrell, 1968; Yoshimoto & Gressitt, 1959, 1963; Yoshimoto *et al.*, 1962*a,b*), or on land by various vehicles (see truck traps below). By adjusting the speed of the vehicle it is possible to control the volume of air sampled, but sampling is not from a point source but from a transect. Ships or aeroplanes have rarely been used to sample aerial populations of mosquitoes, but Bidlingmayer & Schoof (1957), Nielsen & Greve (1950) and Provost (1960) have all used nets pulled by aeroplanes in abortive attempts to catch mosquitoes. Holzapfel & Harrell (1968) list 43 Culicidae as being caught by traps on ships at sea, and illustrate the various types of traps in which insects were caught, such as fixed and wind orientated windsocks, sticky traps, ventilation traps and suction traps.

Ascending nets

Reference must be made to the nets used by Nielsen & Greve (1950) in Denmark to sample swarms of mosquitoes and other Nematocera. They are not drawn horizontally through the air but sample mosquitoes by rapidly ascending. The net is made of tulle and weighs only 125 g; it is 250 cm long, 60 cm across at the opening but tapers to a narrow cylindrical section only 20 cm in diameter. An 8-m length of line from a hydrogen-filled balloon is attached to three equally spaced strings fixed to the edge of the opening. Another fine length of line is attached to the rim of the net and threaded through a loop made 50 cm from the net in the balloon line (Fig. 4.4*d–f*). With this arrangement the opening of the net is placed vertically and does not sample the air as the line is slackened to let the net and balloon rise to the desired height. Then by tugging on the line the net is released and its opening now points directly upwards. By releasing the brake on a drum, on to which the line is wound, the net is allowed to ascend rapidly, about 200 m/min, to sample the air. Finally, by pulling on the line the net is closed and slowly hauled down.

Truck traps

In mosquito studies, moving traps have usually been fixed to motor vehicles (Barnard, 1979; Bidlingmayer, 1966, 1967; Holbrook & Wuerthele, 1984; Loy *et al.*, 1968; Provost, 1952, 1957; Sommerman & Simmet, 1965; Stage *et al.*, 1952; Steelman *et al.*, 1968; de Zulueta, 1950) and are called truck or vehicle traps. Hill (1971), however, used a bicycle mounted trap, while Provost (1960) and Steelman *et al.* (1968) used traps mounted on power boats.

Some of the earliest traps attached to motor vehicles consisted of large cones mounted on either the near or offside front wing (Chamberlin & Lawson, 1945; Stage & Chamberlin, 1945; Stage *et al.*, 1952). De Zulueta (1950), however, used two muslin conical nets with 60-cm openings mounted on poles which extended 2 m beyond the side of the vehicle and were 1½ m above the ground. When the car was driven at 30 km/hr over open savanna country about 20 min after sunset both culicines and anophelines were collected. None of these trapping methods was referred to as truck trap collections, this term was introduced later into the literature.

Several different designs of truck traps have been developed. Bidlingmayer (1961) used a modification of the trap designed by Chamberlin & Lawson (1945), to catch *Culicoides furens*. He later added a few minor alterations (Bidlingmayer, 1966). The trap consists of a pyramidal frame-work of 2 × 2-in wood covered on the inside with glass fibre mesh screening. The opening is 2 ft high and 7 ft wide, and the trap tapers back, about 10 ft to end in a 4 × 4-in opening. The leading edges are made of tempered hardboard. A projection about 15 in long is attached to the top of the trap to support the end of the cloth collecting bag which is tied to the end of the trap. The trap is mounted a few inches above the roof of a vehicle with the front edge projecting over the windscreen (Fig. 4.5*a*). The vehicle is driven at 20–25 mph and at the end of a run, usually of several miles, the bag is quickly removed and replaced by an empty one. It would obvi-

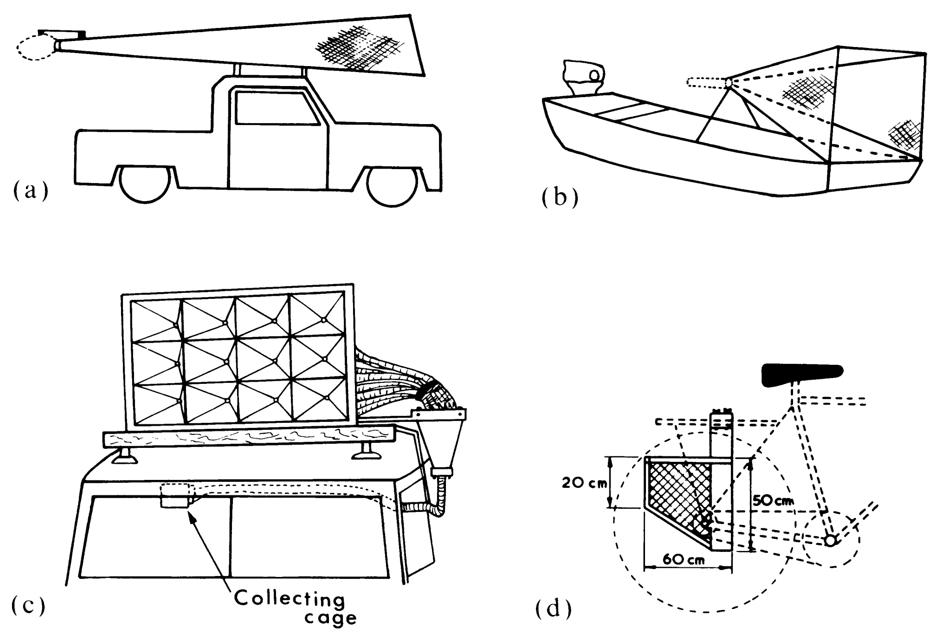

FIG. 4.5. (a) Truck trap (after Bidlingmayer, 1974); (b) trap mounted on power boat (after Steelman et al.*, 1968); (c) truck trap of Sommerman & Simmet (1965); (d) bicycle trap (from Hill, 1971).*

ously be an advantage to fit a cone into the sleeve to prevent the mosquitoes escaping when the vehicle stopped.

In Japan a truck trap similar to that used by Bidlingmayer (1966) was mounted on a vehicle driven at 25–30 km/hr to sample mosquito populations in villages and rice fields. From regular collections made about 3 hr after sunset the seasonal incidence of the four commoner species in the area was obtained. In addition to unfed individuals a number of blood-fed and gravid females were collected, and in the case of *Culex pipiens* these constituted a major element of the catch (Shimizu *et al.*, 1969).

Yoshimoto & Gressitt (1959) soaked the nets in 5% endrin and then sprayed the insides with DDT and pyrethrum to kill the captured insects and prevent them from escaping. Provost (1952) used conical nets mounted both on the roof and front bumper of a vehicle to sample dispersing *Aedes taeniorhynchus*; from a total of 735 truck trap collections 33 259 female and 8432 males were caught. In later collections Provost (1957) used only one trap which was placed on the roof and was 18 in wide and made in the form of an inverted scoop to catch mosquitoes that were swept upwards from the front of the vehicle. This trap caught 344 148 females and 82 287 males of *Aedes taeniorhynchus* in 1176 collections.

Loy *et al.* (1968) designed a lightweight trap weighing less than 25 lb to enable it to be taken as personal baggage on passenger airlines. The trap was constructed of ¾-in aluminium tubing, and the opening of their final model was 5 ft wide and 2 ft high. To reduce the bulkiness of the trap, each of the longer sides was provided with a 2-ft removable section, held in position with sliding pins (split pins). When dismantled and folded the maximum dimensions were 1½ × 2 ft. Nylon netting was used to make the pyramidal collecting funnel, but the anterior 12 in into which the frame was sewn, was made from smooth fabric. A 4-in diameter fabric sleeve was sewn into the apical opening of the trap and glued into a 4-in diameter collecting tube. A standard CDC trap collecting bag was fitted over the other end of the collecting tube. The trap was mounted on top of a frame made of telescopic aluminium tubing. Suction cups and straps were used to secure the trap to the top of almost any vehicle. Guy ropes were attached from the top edge of the trap opening to a convenient structure on the vehicle to help hold the trap in position. In assessing the relative size of mosquito populations the trap was driven over carefully mapped out routes, usually of 5 miles, during crepuscular periods when mosquito flight activities were greatest. Care was taken to sample the population continuously from the beginning to the end of the crepuscular flight period.

In Australia, Dyce *et al.* (1972) used a modified design of this trap mounted on top of a vehicle driven at 15 mph over preselected routes. The small sleeve-like terylene voile collecting bags were removed at 0·5-hr intervals.

Steelman *et al.* (1968) constructed a lightweight trap weighing about 35 lb made from a framework of angular aluminium and covered with glass fibre netting. An 18-in long sleeve at the end of their trap folded on itself when the vehicle stopped, thus preventing the catch escaping. The trap was used on a variety of motor vehicles, and also mounted on the front of a power boat (Fig. 4.5*b*).

This trap proved unsuccessful in catching blood-engorged mosquitoes in Texan rice fields, more were collected by D-vac aspirators (Kuntz *et al.*, 1982). Similarly, although Williams & Meisch (1983) found it collected more mosquitoes and more species (14) than collections with aspirators from vegetation (5), and from artificial resting shelters (6), the proportions of blood-engorged mosquitoes was very low (0·0–2·4%). For example, only 2·2% of *Psorophora columbiae*, the most common species in all collections, were blood-fed compared with 37·1% from D-vac collections and 40·4% from resting stations. In contrast relatively large numbers of blood-fed mosquitoes, especially *Culex annulirostris* and *Anopheles annulipes* were caught in truck traps operating in Australia (Muller *et al.*, 1981).

Sommerman & Simmet (1965) developed a new type of vehicle mounted trap in Alaska in which the mosquitoes were directed into a collecting cage mounted inside the vehicle. The driver was thus able to follow the pattern of collecting as the trap was in use, and could remove and replace the collecting cage without having to get out. The original paper should be consulted for a detailed account of its construction, but the general features are as follows. There is a rectangular funnel opening 36 in wide and 21 in high, but because the catch is diverted down into the front of the vehicle the trap only extends backwards 21 in. Because of this a single funnel is not suitable for catching and retaining the mosquitoes. Instead the opening is composed of 12 small rectangular funnels (7 × 9 in, about 15 in deep) having steep sides (76–78°) and arranged in three rows (Fig. 4.5*c*). Mosquitoes collected in these separate funnels are conducted by 12 flexible plastic tubes into a funnel mounted vertically outside and just above the driver's window. A flexible tube from this 'concentrating funnel' guides the mosquitoes into the collecting cage attached to the sun visor inside the vehicle. The trap was designed to be sufficiently light for one person to handle, yet strong enough to withstand rough roads.

Truck traps have rarely been used outside the USA, but in India Rajagopalan *et al.* (1977) used a trap on top, and another mounted on the side, of a jeep which was driven at 30–35 kph on seven nights along a 11-km stretch of road. A total of 7309 male and 5825 female *Culex quinquefasciatus* were collected, most females were unfed, but there were a few blood-fed, half-gravid and gravid individuals.

In Louisiana a truck trap with a 1·48-m^2 opening positioned 2 m above the ground was driven at 21 kph over a 7·1-km route for 30 min each hour from 1830–0600 hr. The trap sampled 10 480 m^3 of air during each run, and from three such runs caught 527 male and 3597 female mosquitoes belonging to 15 species. The commonest were *Culex salinarius* (58·6%), *Aedes taeniorhynchus* (16·3%), *Aedes sollicitans* (7·8%), *Anopheles crucians* (2·7%) and *Uranotaenia lowii* (2·3%). Most species exhibited peak flight activities just after sunset and before sunrise (Carroll & Bourg, 1977).

Barnard (1979) reviewed the use of truck traps and considered most were complicated and expensive to make, and that the Bidlingmayer (1966) model could not withstand hard use. As a consequence Barnard (1979) described a simple, inexpensive, portable, durable trap that one person could assemble on the roof of a car in about 15 min. The disassembled trap fits into the back of a station wagon-type car or pick-up. The frame of the trap is made of a 2·5-cm diameter thin wall steel conduit with the ends hammered flat and bent at 45° angles and bolted together to form a 190 × 72-cm entrance leading to a rectangular cone of 12·5-mesh/cm of nylon marquisette (Fig. 4.6). The collection cage consists of a 10-cm diameter and 20-cm long galvanised tube connected with a hose clamp to a 50-cm long, 15-cm diameter nylon finely woven cloth bag. The entire trap is about 310 cm long.

Driving the vehicle at 40 km/hr over a 4-km course takes 7 min and about 5500 m^3 of air are sampled. In Colorado in addition to catching 13 species of

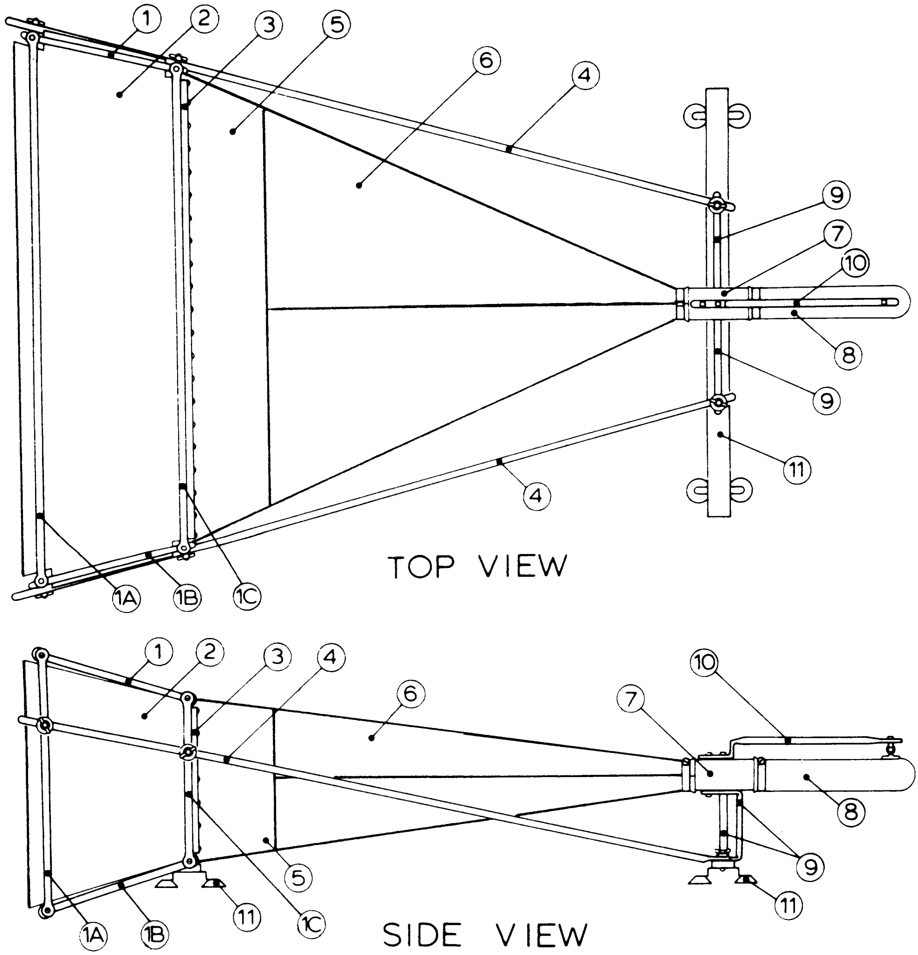

FIG. 4.6. Vehicle-mounted trap: 1 — frame, 1A — leading edge of frame, 1B — cross-member, 1C — trailing edge of frame, 2 — collecting funnel, 3 — retaining bar, 4 — frame support, 5 — net attachment band, 6 — net, 7 — concentrator, 8 — receiving bag, 9 — concentrator support, 10 — receiving bag support, 11 — luggage rack (Barnard, 1979).

Fig. 4.7. Truck trap of Holbrook & Wuerthele (1984) (photograph courtesy of F. R. Holbrook).

Culicoides, the main target insects, *Aedes dorsalis, Aedes nigromaculis, Aedes trivittatus, Aedes vexans, Culex tarsalis* and *Culiseta inornata* were collected.

Holbrook & Wuerthele (1984) also constructed a lightweight (19 kg) portable vehicle-mounted trap. It was fixed in front of a vehicle (Fig. 4.7) to avoid turbulence caused by air passing over the front end of the car (Bidlingmayer, 1966). The frame and supporting upright mounts fixing the trap to the front bumper are made of lightweight metal tubing about 1·9-cm in diameter. The forward and rearward sections of the trap are of light canvas. The 256-cm long middle section is made of fine mosquito netting with an entrance of 195 × 85 cm tapering to a 10-cm diameter opening at the rear which is connected to a removable 30-cm long netting bag. Apparently one person can mount the trap in position within 15 min and dismantle it in 10 min. The longest section of the trap is 112-cm, and all parts are easily packed into a fabric carrying case. Using this trap in Colorado Tsai *et al.* (1989) found that per unit effort, in this instance 1 hr operation per night, truck traps were more effective in catching *Culex pipiens* (mean of 21·6) than either CDC light-traps baited with CO_2 (6·4) or Reiter-type (1983) gravid traps (12·9). Disappointingly only three blood-fed *Culex pipiens* were collected by truck traps. However, truck traps were less effective in catching *Culex tarsalis* (3·4) than light-traps (5·0), but superior to gravid traps (1·1). The ratio of the *Culex tarsalis*: *Culex pipiens* collection with truck traps was 1:6·40, with gravid traps 1:12·10 and 1:1·27 with light-traps. It was considered that light-traps seriously underestimated the population of *Culex pipiens*, although species diversity was greatest in light-traps (15 spp.) compared to eight species caught by both gravid and truck traps.

Clearly a comparison is being made between collections at static points (light-traps and gravid traps) and collections along a transect (3·2 km) by the truck traps.

To study the flight activities and population size of various British simuliids Davies & Roberts (1973) designed a useful trap fitted to a roof rack mounted on a van. The trap has a 91·5-cm wide, 61-cm high entrance which tapers to 10·2 cm diameter at the opposite end. To ensure a smooth air-flow through the trap it is covered with polyester netting having 13·3 meshes/cm and a 50% open area. The lower edge of the trap is positioned 23 cm in front of the leading edge of the van's roof so as to minimise the effect of the slip stream of air over the windscreen. The volume of air sampled depends not only on the van's speed and the cross-sectional area of the trap, but also on wind speed and direction. To measure the actual volume of air sampled an anemometer is fixed in the entrance of the trap. Insects collected by the trap are forced through tubing and delivered into perspex collecting tubes contained in the back of the van, which is driven at 48 km/hr. At lower speeds large insects such as muscids are not forced down into the tubes, while at higher speeds a back pressure is set up which prevents a smooth flow of air through the trap.

The collecting tubes into which the insects are delivered are mounted in a turntable, placed in the back of the van, which is rotated by an electric motor connected to the van's 12-V battery and also to an auxiliary one. At the end of each kilometre run the driver presses a switch on the van's instrument panel which causes the turntable to advance and position a new collecting tube beneath the end of the delivery tube.

A good example of the careful analysis that should be applied to truck trap data is provided by Davies & Roberts (1980) in their studies on simuliid blackflies in England.

Limitations of truck traps

Vehicle-mounted traps sample only the aerial populations of mosquitoes where they are actually used, that is those individuals actually flying over the terrain covered by the trap. Thus large populations of certain species may occur in the general area but be largely missed unless the truck traverses their flight paths. For example, Bidlingmayer (1966) using a truck trap in Florida thought it likely that representative samples were not obtained of *Culiseta melanura* and *Anopheles quadrimaculatus*, species which prefer woodland habitats. With any non-attractant trap mosquitoes will only be sampled which occur in the site occupied by the trap. With traps employing attractants, for example light-traps, mosquitoes may be caught not just from the immediate vicinity of the trap but from a considerably greater area.

The numbers of mosquitoes caught in a truck trap will obviously depend on the time of catching and the mosquito flight times. Bidlingmayer (1966, 1967) proposed that the night might be divided into eight approximately equal periods, the first being from sunset to the end of astronomical twilight. Each of the two periods from the end of twilight to midnight, and from midnight to the beginning of morning twilight are divided into three equal periods, and the final period is from the beginning of astronomical twilight to sunrise. Truck trap collections may have to be made during all eight periods, and also possibly during daylight hours if mosquito populations are to be adequately sampled. However, in many instances collections can be restricted to around sunset, when many mosquito species are most active. During twilight periods truck trap collections can also be divided into short intervals, e.g. 10 min, to study the build up and subsequent decline of flight activities (Bidlingmayer, 1966).

Meteorological conditions, especially wind, will affect the efficiency of catching. Bidlingmayer (1967) found that with winds of 0·1–0·9 mph the catches of female *Aedes taeniorhynchus* and *Culex nigripalpus* were reduced by about 58% of the numbers caught on still nights (wind < 0·1 mph), and by about 80% in winds of more than 1 mph. It is recognised that there is increased flight activity of many species on moonlit nights, consequently, truck trap collections are likely to be greater on these nights, although light-trap catches will usually be less (Chapter 6). However, if collections are restricted to crepuscular periods there may be little, if any, significant difference between catch size according to the phase of the moon (Bidlingmayer, 1967). Bidlingmayer (1974) in an informative paper on the influence of environmental factors, studied the effects of light level, wind speed, humidity, and temperature, as well as characteristics of the trap site, on the numbers of mosquitoes caught in truck traps, and also on the numbers caught by vehicle-mounted aspirators, in suction, bait and light-traps. At least 10 species were caught by all of these traps. All were crepuscular and were two to four times more active on moonlit than moonless nights. Wind velocity of 0·45–0·89 mph reduced the catches to about a third of that obtained in winds of <0·45 mph; temperatures of 16–18°C about halved the catch that was obtained when temperatures were 19–21°C. Only *Culex nigripalpus* and *Aedes vexans* showed a response to higher relative humidities. Apart from environmental conditions, the speed of the vehicle and the shape of its contours will also influence the size of the catch.

In a later paper Bidlingmayer (1985) again discusses the effect of meteorological conditions on truck trap catches. He stresses the great difficulty of measuring day-to-day population fluctuations because of variables such as weather conditions. He also points out that most sampling methods collect mosquitoes at only one or at the most a few specific sites, not along a transect as do truck traps, and because of environmental variations such as in the terrain, it is difficult to interpret catches in terms of the overall population in the area.

Bicycle trap

Hill (1971) found that a trap mounted on a bicycle was useful for collecting mosquitoes during both the day and night from unmotorable terrain in Sarawak. By cycling measured distances along footpaths through villages, rice fields and areas of scrub vegetation at a speed of about 5·8 mph he collected about 250 females of *Culex tritaeniorhynchus* in about 27 min, during which time a distance of 4320 m was cycled. He also expressed his catch as the number caught/1000 m per 10 min. Most mosquitoes were unfed females, but some blood-fed and gravid females were caught, as were a few males. The trap consists of a 60-cm long wooden frame covered with fine wire mesh mosquito netting having an opening 50 cm square tapering to the rear end which is 20 cm square. The trap is suspended from the luggage carrier of a bicycle and positioned adjacent to the rear wheel about 15–20 cm from the ground (Fig 4.5*d*). Hill (1971) found that mosquitoes collected in the trap could not be forced into a collecting bag at its rear, consequently the catch was removed at the end of each run with a battery operated aspirator. Two modifications were suggested, namely that if the trap was mounted on the front wheel then a larger one could be used and there would be less turbulence around the mouth of the trap; secondly, if the trap was mounted on a small motorcycle it would be easier to handle and maintain at a constant speed.

Remote controlled planes

The military have for some time used remotely piloted vehicles (often planes) for surveillance (= spying!), guiding rockets to the enemy and jamming radar, but large model planes can also be used in entomological research to spray insecticides, and to trap insects (Benzon *et al.*, 1986; Kaniuka, 1985). Gottwald & Tedders (1986) described a 2·04-m long model biplane having a 2·44-m wingspan which was powered by a 4-hp chainsaw motor, controlled in flight by a 7-channel FM radio. A conical 19-cm diameter, 35·6-cm long net, which could be opened and closed by remote ground control, was placed on either side of the fuselage between the upper and lower wings. Flying on three occasions in Georgia, USA at heights of 2–54 m over pecan and peach trees the plane caught a large variety of insects including two mosquitoes (Tedders & Gottwald, 1986).

Reling & Taylor (1984) described a collapsible 68·6-cm diameter net for trapping aerial populations that sampled some 647 m^3 air/min. The net is inexpensive and can be fitted, with virtually no modification, to a light monoplane aircraft. It proved useful in the USA for catching leafhoppers.

In attempts to catch phlebotomine sandflies in France Killick-Kendrick (1986) flew a radio-controlled model plane having a 4-stroke engine and wingspan of 2·2 m at heights of 10–39 m. A 155-cm diameter 12-cm long pod supporting 30- or 75-cm long gauze nets was fixed under each wing. Although sandflies were not caught, six Diptera, including a *Culicoides* female, were collected in 13 short flights.

In some situations there is probably some potential for sampling mosquitoes at heights of about 10–50 m by radio-controlled model planes, as well as it being considerable fun! But as Killick-Kendrick (1986) points out an experienced pilot is needed for take-off and landing if the plane is not to crash.

Sticky traps

General considerations

Sticky traps can be divided into two basic types, attractant and non-attractant. Examples of the former are those employing carbon dioxide (Gillies & Snow, 1967; Wilson *et al.*, 1966), a bait animal (Disney, 1966) and traps made of a particular colour or shape that attract insects (Allan & Stoffolano, 1986; Broadbent 1948; Snoddy, 1970). Some of these traps are described elsewhere in the book; this section is devoted to non-attractant traps. With these, insects are caught either as they alight or are blown on to sticky surfaces.

A variety of sticky compounds have been used including commercial tree banding resins ('Bentley's Tree Grease', 'Tanglefoot', 'Stop Moth', 'Stickem', 'Deadline', 'Tack Trap', etc), various greases, castor oil and other oils, mixtures of oils and greases and commercial sticky adhesives. Greases and oils are not such strong adhesives as resins and usually only relatively small insects will be trapped, but if the correct formulation is used mosquitoes can be caught (e.g. Provost, 1960). Bird repellents such as 'Beacon' (Walsh, 1980), and 'Roost-No-More' (West *et al.*, 1971) have also been used on sticky insect traps. Ryan & Molyneux (1981) compared the efficiency of 23 different adhesives in the laboratory and found that polybutene adhesives (e.g. 'Oecotak', 'Hyvis') were the best. They present useful tables giving the manufacturer's addresses, physical, chemical and handling properties of the adhesives, their solvents, and numerous references to the 23 adhesives they tested, as well as to three untested ones ('Tangletrap', 'Tack Trap' and 'Stickem'). In England I have found that 'Hyvis 2000' and 'Rat Varnish' are very suitable for retaining mosquitoes—and also heavier insects, and moreover can be used underwater to trap mosquito larvae (Service, 1984; see pp. 136–7).

Although tree banding resins are the most efficient for catching a wide variety of different sized insects the catch is difficult to remove, and with many resins insects can be satisfactorily removed only by heating and scraping them off. With greases and oils insects can usually be picked off and cleaned in benzene, petrol, methanol, isopropanol or a variety of other solvents. One of the most common sticky materials used in commercial adhesives is polyisobutylene, which being non-polar is not easily dissolved in polar solvents such as acetone. Murphy (1985) lists the following solvents as best for removing insects from sticky traps using polyisobutylene adhesives: toluene, heptane, hexane, xylene, ethyl acetate, and various concoctions of these. Other suitable substances are fingernail polish remover and methylchloroform (1,1,1-trichloroethane) which is the modern substitute for carbon tetrachloride as a domestic grease remover. Less effective solvents are petrol and kerosene which linger on insects for a long time. After dissolving the adhesive with one of these solvents the excess solvent should be removed with filter paper and the insects washed in ethylene glycol ethyl ether (cellosolve) for 1 hr or longer (even overnight) to remove the solvent. The cellosolve is then removed by putting the insects in xylene for 30–60 min, after which the specimens can be placed on blotting paper, allowed to dry and then pinned.

It is often difficult to get an adhesive of the correct viscosity and tackiness. If the adhesive is too thin it tends to run down the coated surface and get washed off by rain. High temperatures may also cause greases and oils to become fluid. When the mixture is too thick many insects alighting on the sticky surface are not held and fly off again, only those blown forcibly on to the surface are trapped. In field experiments Browne & Bennett (1981) found that coating trap surfaces with 'Tanglefoot' was ineffective in catching mosquitoes (*Coquillettidia perturbans, Aedes cantator* and *Aedes punctor*) because they tended to hover around the target and to 'test' it with an extended leg, which on encountering a sticky surface resulted in reversed flight and escape. In certain situations there may be a problem with traps becoming covered with extraneous material such as dust, sand, seeds and even unwanted insects.

Strong (1987) described a very cheap and simple system for dipping cardboard, wooden or metal panels in adhesives, such as 'Stickem Special' and 'Sticky Stuff' to coat them. Adhesives could be applied to as many as 140 panels per hour.

Different types of sticky traps

Sticky adhesives can be applied to flat, horizontal or vertical surfaces, e.g. glass plates, boards and screens. Such sticky traps are usually directional, but if mounted at right angles to a wind vane they will trap windborne insects. Furthermore if four sticky flat surfaces are mounted at right angles to each other then mosquitoes from all directions will be caught. As long ago as 1916 Le Prince & Orenstein figured and described such a trap, which was conceived by Mr Quimby, to study flight direction of mosquitoes.

Sticky traps can be placed in various places, such as under the eaves of village huts, near or over rodent holes and amongst vegetation to sample mosquitoes resting in these sheltered situations. More usually, however, they are used to sample aerial populations and most mosquitoes are caught as a result of wind impaction. In Texas, Gordon & Gerberg (1945) used 20 × 20-in screens of 18-mesh copper netting mounted in wooden frames to study mosquito dispersal. To determine flight direction four similar screens were slid into grooved arms set at right angles to each other on a post. The centre of each screen was about 5½ ft above the ground. Only a light coating of 'Tanglefoot' was applied to avoid closing the holes in the screens. The five mosquito species caught in order of abundance were *Aedes sollicitans, Anopheles quadrimaculatus, Aedes taeniorhynchus, Psorophora confinnis* and *Culex quinquefasciatus*; 88% came from the southeast which was the direction of the prevailing winds and the largest breeding area in the vicinity.

In Florida Haeger (Provost, 1960) used 22-in cylindrical nylon nets coated with an adhesive (1½ lb amber gear grease, 12 pints No. 20 motor car oil and 1 pint mineral spirits) and caught 355 adults of *Aedes taeniorhynchus* during the short period of evening exodus from larval habitats. The following evening rectangular sections of mosquito netting were mounted in 1 × 2 ft aluminium frames, coated on both surfaces with adhesive, and suspended in pairs at right angles to each other at heights of 10, 20 and 30 ft. From 34 nets a total of 176 *Aedes taeniorhynchus* were caught during mass dispersal of adults from their larval habitats (Provost, 1960). Males represented 26% of the catch, although on the previous night using cylindrical sticky traps they formed 79% of the catch. On both occasions the proportions of males on the sticky nets were less than obtained by collecting resting mosquitoes, thus indicating that not all emerging males dispersed.

A disadvantage of solid flat surfaces is that eddies usually develop around their edges (Fröhlich, 1956) and consequently not all insects blown towards them are caught. Cylinders or mesh screens are more efficient in catching windborne insects. Cylindrical sticky traps, as originally developed by Broadbent (1946) to sample aphids, are more efficient than most flat surfaces in sampling windborne insects because the air flows more smoothly past them than with solid flat surfaces; in general they become more efficient as their diameters decrease. They do not appear to have been used to sample mosquito populations but might prove useful in certain situations. The best procedure is not to coat the trap with an adhesive but to apply this to a sheet of paper or plastic that is wrapped around the trap, which can consist of a test tube, tin can, glass jar or a length of plastic or drain pipe. Such sticky surfaces can be readily removed and replaced with new ones.

Rohitha & Stevenson (1987) made an automatic sticky trap for sampling aphids that changed a sticky cylinder daily for 7 days. Basically a vertically mounted long section of plastic tubing houses small (188-mm long) sticky cylinders, one of which is dropped down on a central rod into an exposed situation where it catches aphids. After 24 hr a simple cog and notch arrangement operated by a 7-day clock (ex thermohydrograph) allows this sticky cylinder to drop into a lower section of plastic tubing, while at the same time another sticky cylinder descends to replace it.

Gregory (1951) showed that the efficiency of a vertical sticky cylinder for catching fungus spores was related to a non-dimensional function *k*:

$$k = \frac{V_s V_0}{rg}$$

where V_s = wind speed, V_0 = terminal velocity of the spores, r = radius of the cylindrical trap and g = gravitational acceleration, i.e. 9·81 m/s^2. Taylor (1962*b*) showed that small insects, up to about ¼ in long, behave as inert particles in wind speeds of more than 2 mph. Apparently only in winds of less than this do small insects exert any control over whether they are caught on cylindrical sticky traps. Aerodynamic efficiency increases steeply with increasing wind speed and approaches a constant value in winds over 6 mph. Taylor presented a table of conversion factors (in logs) which when added to the log catch per hour of insects caught on a 5-in diameter, 12-in long non-attractive sticky cylinder gave log density per 10^6 ft^3 of air. These conversion factors apply only to traps of this size and only to insects up to about ¼ in in length, but this would include a number of mosquito species.

Water traps

These consist of metal, glass or plastic receptacles of various shapes, sizes and colours containing water to which a wetting agent has been added so that when insects rest on, or fall into, the water they are wetted and trapped. Small amounts of preservatives, such as formalin, can be added to the water to help preserve the catch (see Southwood, 1978). It seems unlikely that as such these traps will be of much value in catching mosquitoes. But Grigarick (1959) used floating water traps to help catch insects settling on water. Possibly, such traps, or even the addition of a wetting agent direct to the water of small larval habitats (e.g. containers, small ground pools), might wet mosquitoes that rest on the water surface to oviposit. The relationship between numbers caught and trap areas was linear on a $\sqrt{} \times \sqrt{}$ scale for aphids, with trapping efficiency per unit area decreasing with larger traps (Costa & Lewis, 1968). It was concluded that at least some of the aphids were visually attracted to the traps.

Suction traps

General considerations

Insect suction traps measure the aerial density of insects at the site of the trap. Because they do not employ any attractant the differences between numbers of various insects caught should reflect their natural densities. They are thus usually considered to give unbiased samples (Service, 1969; Taylor, 1962*a*), but with some insects this may not be completely true. For example, Banks (1959) considered that small suction traps might be selective in catching syrphids as some of the larger species are strong fliers and might consequently escape capture. Way & Banks (1968) in fact found that the number of syrphids caught in 'Johnson–Taylor'-type traps (Johnson, 1950*a*; Taylor, 1951) could not be correlated with the numbers caught on sticky traps. Also, the proportions of *Chrysops caecutiens* and *Haematopota pluvialis* caught in suction traps differed markedly from their proportions in human bait catches (Service, 1973*a*). It was thought that the actual traps might be visually attractive differentially to the two species. In the USA Bidlingmayer and his colleagues have conducted several field experiments showing that their rather large L-shaped suction traps (Figs 4.8*e*, 4.14), are visible to mosquitoes, as are surrounding bushes and trees. They concluded that trap catches are influenced by these visible cues (Bidlingmayer & Hem, 1979, 1980; Bidlingmayer *et al*., 1985). Similarly Snow (1975) believed that some, but not all, species of mosquitoes tended to avoid the much smaller 'Vent-Axia' suction traps he used in The Gambia. Bidlingmayer also considered that even moderate winds reduced the numbers of mosquitoes caught in his suction traps (Bidlingmayer, 1974; Bidlingmayer & Hem, 1980; Bidlingmayer *et al*., 1985). For more details on the effects of visual responses and wind speed on catches of mosquitoes in Bidlingmayer traps see pp. 333–6. Nevertheless despite these possible limitations suction traps probably give less biased samples of mosquitoes (Bidlingmayer, 1967; Gillies & Wilkes, 1976; Service, 1969, 1971*a*; Snow, 1975) than other sampling methods. However, truck traps will also give 'unbiased' catches, the only important variables affecting their catch size, apart from mosquito numbers *per se*, will be weather conditions which affect flight behaviour.

In addition to measuring absolute aerial densities suction traps can be used to study vertical distribution, diel flight activities, seasonal incidence, and flight direction. Because they are non-attractant, visual cues excepted, few mosquitoes will be caught in the traps when populations are low, consequently prolonged sampling may be necessary if statistically reliable numbers are to be obtained. It must be emphasised that suction traps do not measure or sample adult populations of mosquitoes as such, but only that fraction which is actively flying; it is the aerial population that is sampled. Consequently, the numbers of mosquitoes caught in the trap depends both on the size of their population and their flight activity. It is therefore not surprising that unfed females constitute the greatest proportion of mosquitoes that are usually collected by suction traps.

The volume of air sampled by a trap depends on both the diameter and speed of the fan and also the angle of pitch of its blades. The same air speed can be obtained with a steep pitch blade angle and slow motor as with a small pitch angle and a fast motor, but as a fast motor uses less power and is consequently lighter, the best combination is a small pitch angle and a fast motor. When traps are operated from a long length of cable sufficiently thick wire should be used to minimise voltage drop, which may otherwise slow down the fan and result in a smaller air sample. The total impedance is greater in a 3-phase than 1-phase motor of the same power, thus the proportion of voltage lost is less with a 3-phase motor. They also have the advantage of being considerably lighter than 1-phase motors. All traps should be efficiently earthed. Lightweight materials are essential when large fan blades are used.

Although the volume of air sampled by specific fans may be given in publications it is advisable to check the air displacement of a fan to be used in a trap, either with the manufacturer or in the laboratory (e.g. Loomis, 1959; Macauley *et al.*, 1988; Mulhern, 1953; Taylor, 1955, 1962*a*; Wainhouse, 1980), because of the variability between similar traps, and because a new model may have been produced which gives an increased air flow. In certain studies, however, it is unnecessary to know the volume of air sampled so long as all traps are sucking in the same, but unknown, quantity of air.

Two very different designs of suction traps have been mainly used to sample mosquitoes. Namely, vertical models employing a 22·9-cm 'Vent Axia' fan based on the traps of Johnson (1950*a*), Taylor (1951) and Service (1971*a*), these have been used in Britain and The Gambia (Figs 4.8*a,b*, 4.9), and the much larger L-shaped traps of Bidlingmayer (1964, 1967) used in the USA in which the 24-in fan is mounted on its side (Fig. 4.8*e*). A few other traps which have occasionally been used to sample mosquitoes, or have the potential to do so, are described towards the end of this chapter.

'Johnson-Taylor' exposed cone traps

These traps were designed at Rothamsted Experimental Station, England, to sample aphids mainly near the ground or in areas with little wind. The original trap was devised by Johnson (1950*a*) but its design and construction was improved by Taylor (1951). Both these papers should be consulted if a trap with dropping discs to segregate the catch into time intervals is to be constructed. These are, however, commercially available (Fig. 4.8*a,b*) having 22·9 or 30·5-cm fans. The essential components are as follows.

A 22·9-cm diameter 'Vent-Axia' fan, with the grill over the opening removed is mounted vertically. It is important that an impeller-type fan is used, i.e. a fan with reversed blades, so that the air is sucked down into the trap and not blown out. The unit is mounted with the fan blades uppermost and the motor under-

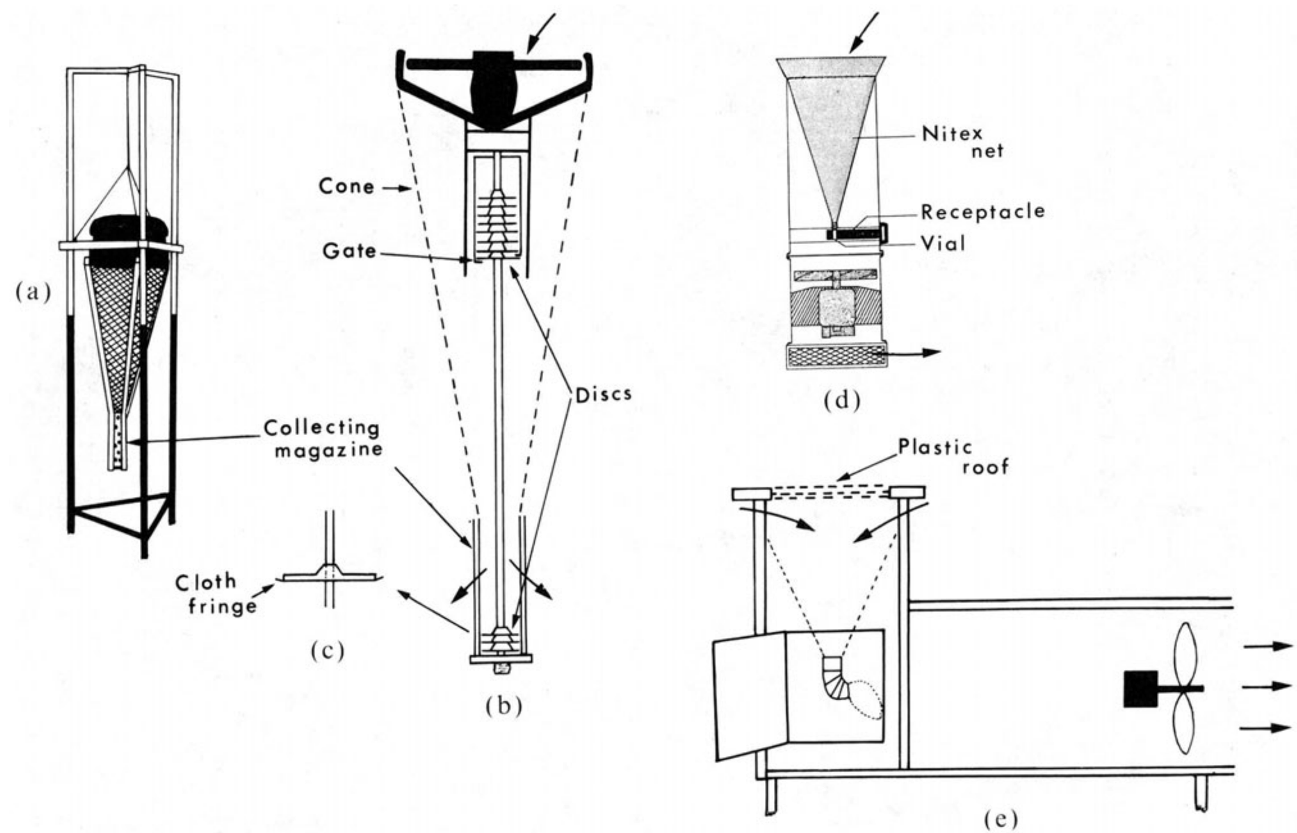

FIG. 4.8. (a) Johnson–Taylor suction trap; (b) Johnson–Taylor trap showing arrangement of fan, cone and discs; (c) single disc with cloth fringe; (d) large diameter suction trap (from Holzapfel & Harrell, 1968); (e) suction trap of Bidlingmayer (after Bidlingmayer, 1974).

neath. The encasement surrounding the motor and fan usually has ledges and grooves and these should be filled in, otherwise insects sucked in by the fan get trapped in them and are not collected. Attached to the bottom of the fan is a copper, or monel metal, 21-in long cone made of 26-mesh gauze (Fig. 4.8*b*). Three equally spaced metal struts run down the outside of the cone and extend beyond it to hold in position the metal cylindrical casing which houses the collecting magazine. A central 24-in long rustless metal guide rod is bolted to the base of the motor casing and projects downwards through the mesh cone to extend about an inch beyond the bottom of the collecting magazine. A solenoid and disc release mechanism is mounted just beneath the motor. The discs which segregate the catch are pushed up the central rod and stacked within a rectangular gate mechanism. When the solenoid is activated one of the jaws at the bottom of the gate moves sideways allowing the disc resting on it to drop down the central rod into the collecting magazine. Each disc is made of brass or stainless steel, is 1¼ in in diameter and has a central collar ¼ in high and 5/16 in in diameter which keeps the discs apart and through which is the hole by which it is pushed up the central rod. A piece of cotton cloth is glued on to the lower surface of each disc and cut to leave a fringe of about 1/16–⅛ in projecting beyond the disc (Fig. 4.8*c*). When a disc is released and falls down the central guide rod this fringe brushes against the walls of the collecting magazine ensuring that small insects are not missed but trapped between successive discs. It is preferable to use shellac varnish to stick the cotton on to the discs as this is not softened by ether, oil or many other solvents, except alcohol, which might come into contact with the discs. The discs should be soaked in 1–3% pyrethrum solution or other killing agent. Insects are drawn into the trap by the fan and are gently blown down the collecting cone and deposited on to an oil film smeared on the upper exposed surface of the last fallen disc. They are killed by the killing agent and are sealed off by the next disc that descends the rod. When all (24) discs have fallen they are removed by placing an 8-in long monel rod underneath the projecting central rod of the trap and carefully allowing the discs and magazine to slide on to it. A new set of discs is then pushed up the central rod past the jaws of the solenoid operated gate and an empty magazine screwed into position at the base of the trap. If the discs have not been treated with pyrethrum the magazine can be placed in a plastic bag and the catch anaesthetised, after which the discs are carefully slid from the short rod in the magazine and the segregated catch identified. The discs are cleaned before re-use. A light application of thin oil should be run down the short rod of the magazine when it is stacked with discs, so that their central holes are lubricated and they therefore fall smoothly down the central rod of the trap. Alternatively, the central rod can be unscrewed, cleaned with metal polish and polished with a silicone wax.

The traps are operated from mains electricity and a control box allows the fans to work at slow, normal or boost speeds. Unless mosquito densities are high, traps are best operated on the fastest speed as this samples a greater volume of air. An electromagnetically operated time switch allows the discs to be released at pre-set time intervals. Burgess & Muir (1970) described how a simple piece of additional mechanism can be fitted to the 'Sangamo–Weston' time switch, which is usually used with the complete trap unit, to enable the catch to be divided into 12-hr intervals.

Several simple precautions are needed for the efficient operation of the traps. Great care must be taken not to bend the central rod in the trap otherwise the discs will not fall freely. The interior of the fan casing must be kept clean otherwise from time to time large numbers of insects may become squashed on the inner surface of the casing surrounding the fan. This may build up to such an extent that the fan is stopped, which results in the motor overheating and may cause it to burn out. In wooded areas leaves may lodge in the trap and either prevent the fan from turning or stop the discs descending. It is essential that the monel mesh cone of the trap is kept clean. If dirt is allowed to accumulate on the mesh this may affect the smooth flow of air through the trap which is essential if the catch is to be related to the volume of air sampled. These types of traps having an exposed gauze collecting cone should not be used in situations with cross winds of more than about 10 mph, otherwise there is a significant reduction in the intake of air. This can be minimised, however, by enclosing the cones in a cylindrical tube.

These traps have been used in England to obtain the seasonal incidence and diel flight periodicities of several British mosquitoes (Service, 1971*a*). They have also been valuable in detecting the presence of adults of several anthropophagic species before they are orientated to blood feeding and are caught in bait catches (Service, 1973*b*).

Larger traps with enclosed cones (aerofoil and airscrew traps)

Larger and more powerful traps have been designed for sampling insects in exposed situations such as high up in the air where wind speeds are more likely to affect the sampling efficiency of the trap. More powerful traps, sampling a greater volume of air, are also needed in situations where insect density is low. Four large traps have been described by Johnson & Taylor (1955*a–c*), the most useful being the 'Enclosed' 12 and 30-in traps. The 12-in trap has an aerofoil fan mounted in a 14-in diameter, 4-ft long steel cylinder and delivers about twice the volume of air as the 12-in 'Vent-Axia' fan. The larger trap employs a 30-in lightweight airscrew fan mounted in a 2½-ft diameter, 7½-ft long cylinder and delivers about five times the air as the 12-in aerofoil trap. Because insects get damaged if they pass through the fan blades of these high speed fans, the fan is positioned below the collecting cone and segregating device. An essential feature of the trap is that the collecting cone is enclosed within a cylindrical duct made either from sheet metal or rubberised fabric stretched over a light metal frame. By shielding the cones the effect of cross winds on sampling efficiency is greatly reduced.

Holzapfel & Harrell (1968) described a 90-cm diameter suction trap with a conical nitex funnel-shaped net surrounded by an aluminium cylinder (Fig 4.8*d*). A 1-h.p. 1-phase electric motor operating a tube axial fan was placed below the collecting cone and displaced some 6800 m^3 air/hr. Insects did not pass through the fan but collected in a vial held in place by a plastic receptacle which was removed by sliding it horizontally from the trap. When used at sea the fan tended to reverse its direction when the wind was more than about 22 mph. To increase the volume of air sampled, a metal scoop provided with a wind vane was fitted on top of the trap.

In Texas an enclosed suction trap of the Johnson–Taylor (1955*a*) design and having an 18-in diameter fan, was modified to incorporate a turntable containing pint-capacity glass jars half-filled with ethylene glycol (car antifreeze) as a preservative. This allowed the catch to be separated into 2-hr intervals (Goodenough *et al.*, 1983). The trap used a more powerful tube axial fan (1·1 kW) (i.e. 1·5 h.p.) than the Johnson–Taylor trap and sampled about 4500m^3 air/2-hr sampling period, as against about 3000 m^3 for the original Johnson–Taylor trap.

Allison & Pike (1988) describe a home-made enclosed type of suction trap having an 85-cm long, conical net leading to a collecting jar, both of which are enclosed within a 1·5-m length of 38-cm diameter PVC tubing. On top of this a 30-cm diameter 4-m length of PVC tubing is fixed to act as a chimney and sample insects about 8 m from the ground. A three-bladed fan attached to a motor draws the catch down into a collecting jar.

Rothamsted insect survey trap

This trap was designed to enable insects to be sampled at considerable heights without having to construct any complex supporting mechanisms, such as a steel tower (Taylor & Palmer, 1972). It consists of a 30-ft tall, 10-in diameter plastic 'chimney' mounted on a 10-ft high, 30-in square wooden box which contains a centrifugal fan at its base. This type of fan is chosen because it ensures an almost constant air intake in most wind speeds, and also when the gauze collecting cone at the bottom of the trap becomes partially blocked by dust and dirt. Insects which are sucked down the tall chimney are collected in a bottle attached to a collecting cone. To reduce the speed on insect impaction, which can be as much as 35 mph at the base of the trap, the cone has a large surface area. The trap samples 101 040 ft^3 air/hr.

Macauley *et al.* (1988) made a later version of this trap. Their trap consists of a 9·2-m length of 244-mm diameter plastic pipe with a flared inlet positioned 12·2 m from the ground, while the other end is placed on top of a 3-m high box containing a centrifugal fan, and the necessary filtering and storage devices. The inlet air speed greatly exceeds insect flight speed, i.e. >50 km/hr, to give a sample volume of 45 m^3/min. Air flow measurements can be made with a Lambrecht direction velocity metre which has a Prandtl-type pitot static tube. When readings are used in conjunction with tables supplied by the fan's manufacturer air flow through the trap in m^3/min is obtained. But this process likely overestimates air flow by more than 10%. According to Winternitz & Fischl (1957) a more accurate measurement is derived from

$$V_m = 1/5\,[V_{0\cdot5} + 2\,(V_{0\cdot081} + V_{0\cdot919})]$$

where V_m = mean velocity and $V_{0\cdot081}$, etc. are velocities at distances of 0·081, 0·5 and 0·919 diameters from one wall of the trap. Errors are approximately within ±1%.

Schaefer *et al.* (1985) used radar methods and the remote sensoring IRADIT infra-red system to measure aerial densities of insects near the Rothamsted

Insect Survey (10-in diameter) traps positioned with their inlet at 12·2 m, and aerofoil traps (12-in diameter). The aim was to study the effectiveness of these suction traps in relation to increasing wind speeds, such as when traps are used at elevations or in exposed areas.

Simple 'Vent-Axia' traps

When it is not necessary to divide the catch of mosquitoes into time intervals a much simpler trap than the 'Johnson–Taylor' one, without any segregating mechanisms, can be used; the catch being removed daily or at longer intervals (Gillies & Wilkes, 1976; Service, 1971*a*,*b*, 1974, Snow, 1975, 1977). A simple but efficient suction trap can be constructed from a 6, 7½, 9 or 12-in 'Vent-Axia' fan made for window mounting; at boost speeds these fans sample 12000, 18000, 30000 and 62000 ft^3 of air/hr. First, the outer grill is removed, then any recesses or ledges near the fan blades are covered over and the fan unit inserted into a circular hole cut out from a piece of plywood (Fig. 4.9). A monel gauze collecting cone (B) is attached to the board underneath the fan and a small fine mesh bag (C) is tied to the bottom of the cone to collect the mosquitoes. Two 1-in holes are drilled at opposite ends of the board and lengths of ⅝-in galvanised tubing inserted and pushed into the ground. By securing the board to the tubing by small adjustable clamps (e.g. 'Klee-Klamps') its height can be easily altered,

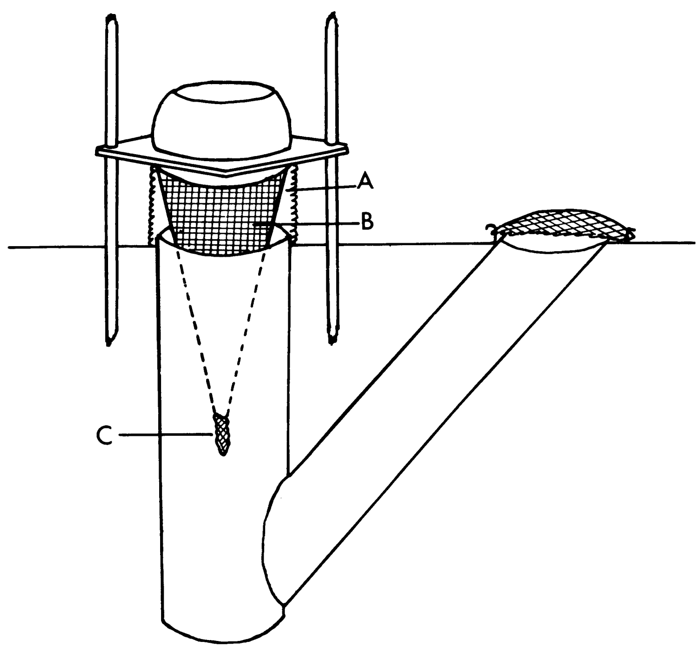

FIG. 4.9. A 9-in diameter suction trap with cone projecting into plastic tubing imbedded in the ground: A — flexible tubular ducting, B — mesh collecting cone, C — collecting bag (after Service, 1971a).

thus allowing the trap to be used at various heights. Wire from the trap enters a control box which allows the use of three fan speeds. Control boxes from a number of fans can be mounted within a waterproof metal box. A length of flexible tubing (A), having a diameter several inches larger than the base of the collecting cone (B), can be attached underneath the plywood board to enclose the cone and thus reduce the effect of cross-winds on sampling efficiency. However, if the traps are used in sheltered positions, such as near the ground or amongst the shelter of vegetation this may not be necessary.

Trap inlets must be positioned near the ground to sample mosquitoes flying near the ground. In very dry areas this can be achieved by just digging a hole and lowering the trap into it, in which case care must be taken that the filtered air exhausted from the trap is conducted away from the fan inlet and not resampled, thereby reducing the sample volume. For example, Snow (1982) and Gillies & Wilkes (1976) were able to place their 22·9-cm 'Vent-Axia' traps in a 1-m^3 pit during the dry season in The Gambia. Two shallow trenches from the pit allowed exhaust gases to escape. But in many areas the ground is waterlogged and holes rapidly fill with seepage water. To overcome this the collecting cone can be placed in a length of plastic or metal tubing. To ensure a smooth flow of air through the trap (Service, 1971*a*) another section of smaller diameter tubing is welded on to it near the base before it is placed in a hole dug in the ground (Fig. 4.9). It may be necessary to hold the tubing in position with ropes while the earth is tightly packed around it. The opening of the exhaust vent should be covered with plastic mesh to prevent small animals slipping down the tubing. A small amount of rain water may accumulate at the bottom of the tubing but the air blowing through the trap helps to evaporate this; however if too much forms it can be pumped out. It is essential that any water that does collect at the bottom does not become contaminated with organic debris, otherwise large numbers of gravid flies may be attracted and become squashed on the inside of the trap.

If the shape of the collecting cone is altered or enclosed within a cylinder it is advisable to check that there is still a smooth flow of air through the trap. This is very simply done by producing smoke at the entrance of the trap and watching its passage through the trap. Titanic chloride streamers or Bee Keeper's smoke generators are useful. Alternatively smoke can be produced by burning corrugated paper soaked in potassium chlorate. The manufacturers' specifications of the volume of air displaced by a trap may be reduced when a collecting cone is added, but Taylor (1955) found that with the 9-in trap this is usually negligible.

Simple 'Vent-Axia' suction traps without any segregating device were used for several years to study the behaviour of British mosquitoes (Service, 1971*a*, 1974) and *Culicoides* (Service, 1971*b*, 1974), while in The Gambia they have been used to catch mosquitoes flying in different directions and at different heights (Gillies & Wilkes, 1976; Gillies *et al.*, 1978; Snow, 1975, 1977, 1982). Othertimes they have been used to study the behaviour of mosquitoes attracted to human baits (Gillies & Wilkes, 1978). Their 'Vent-Axia' fans were sometimes placed on metal scaffolding towers at different heights (Fig. 4.11) (Gillies & Wilkes, 1976; Snow

1975, 1982), or very near the ground (10–20 cm) (Gillies *et al.*,1978; Snow, 1982).

Trap efficiency and absolute densities

Taylor (1962*a*) made a critical and very valuable evaluation of the absolute efficiency of insect suction traps. Among the factors considered were the effect of wind speed, insect size and size of the traps. By taking these factors into consideration Taylor (1962*a*) was able to derive the following formula for calculating the efficiency of any trap with regard to the insects being caught:

$$E = (w + 3)\ (0{\cdot}0082\ C_e - 0{\cdot}123) + (0{\cdot}104 - 0{\cdot}159 \log i)$$

where E = log efficiency, w = wind speed in mph, i = insect size in mm^2 (obtained by multiplying body length by wing span), and C_e = coefficient of efficiency of the trap, calculated by dividing the cube root of the volume of air sampled per hr by the square root of the fan diameter (in inches) thus:

$$C_e = (\text{vol. air sampled in ft}^3/\text{hr})^{1/3} \div (\text{inlet diam. in inches})^{1/2}$$

Now the catch of mosquitoes can be converted to aerial density by dividing the numbers caught by the volume of air sampled, but remembering that an adjustment to the standard air-flow through the trap may be necessary if traps are used in exposed conditions where wind speeds exceed about 5 mph (Taylor, 1955). This value is then corrected for the inefficiency of extraction of mosquitoes by the above formula, which gives a negative value in logs by which the catch of mosquitoes is less than the real density. This calculated value, known as the conversion factor (log f), is added to the log catch to give estimated absolute aerial density thus:

$$\text{Log density per } 10^6\ \text{ft}^3 \text{ air} = \text{log catch} + \text{conversion factor (in logs)}$$

The use of anitlogs gives actual densities.

Taylor (1962*a*) gave tables of conversion factor (log f) for different sized insects and wind speeds (0–10 mph) for 9, 12, 18 and 30-in traps. These values are added to the log catch to give aerial densities per 10^6 ft^3 air, thus eliminating the need to work out the values by the above formulae. Southwood (1978) also presents these tables for a 9-in 'Vent-Axia' fan and 18-in propeller trap. Unfortunately, because the manufacturers have increased the air-flow through the traps, the tables are no longer applicable. An added complication is that the tables of log f supplied by the manufacturers of the 9- and 12-in 'Johnson–Taylor' suction traps are incorrect. A new set of values, kindly supplied by Dr L. R. Taylor, is given here for the 9- and 12-in suction traps (Tables 4.1 & 4.2). It must be remembered that these values refer to fans working at normal speed. If a fan operates at a higher speed then the difference between the logs of the volume of air sampled per hour at normal and boost speeds must be *subtracted* from the published conversion factor. Fans used at lower speeds have the differences between the logs of the volumes of air sampled *added* to the conversion factor.

As is to be expected individual traps of the same size may differ slightly in the volume of air they collect (Taylor, 1955) and this can produce small, but often

TABLE 4.1
CONVERSION FACTOR (LOG *F*) FOR 12-IN 'VENT-AXIA' FAN AT *NORMAL* SPEED

Insect size (mm^2)	*Wind speed (mph)*				
	0–2	2–4	4–6	6–8	8–10
1–3	1·58	1·69	1·81	1·92	2·03
3–10	1·66	1·77	1·89	2·00	2·11
10–30	1·74	1·85	1·97	2·08	2·19
30–100	1·82	1·93	2·05	2·16	2·27
100–300	1·90	2·01	2·13	2·24	2·35
300–1000	1·98	2·09	2·21	2·32	2·43

TABLE 4.2
CONVERSION FACTOR (LOG *F*) FOR 9-IN 'VENT-AXIA' FAN TRAP AT *NORMAL* SPEED

Insect size (mm^2)	*Wind speed (mph)*				
	0–2	2–4	4–6	6–8	8–10
1–3	1·81	1·92	2·04	2·15	2·26
3–10	1·89	2·00	2·12	2·23	2·34
10–30	1·97	2·08	2·20	2·31	2·42
30–100	2·05	2·16	2·28	2·39	2·50
100–300	2·13	2·24	2·36	2·47	2·58
300–1000	2·21	2·32	2·44	2·55	2·66

Tables 4.1 and 4.2 refer to the commercially available 'Johnson–Taylor' suction traps (Messrs. Burkard, Rickmansworth, Herts., England).

significant, differences between the numbers of mosquitoes they collect. Taylor (1962*a*) considered that with 9- and 12-in 'Vent-Axia' fans a difference in catch size of about 6 and 2%, respectively, could not be attributed to real differences in population size. If it is not possible to measure the air-flow through individual traps, then when a number are used their positions should be alternated to minimise individual differences in the amount of air they sample.

It may not always be necessary to convert the catches in the traps to absolute densities. For example, flight periodicities can be studied simply by using the numbers caught each hour; similarly, relative change in population size can be recorded without calculating absolute population size. Since doubling the size of an insect only changes the efficiency of a trap by about 5% (Taylor, 1962*a*) direct comparisons can be made between the numbers of different mosquitoes caught if they do not differ greatly in size. Wind speed will be the most important single factor influencing the size of the catch.

Electric grids and flight direction

Gillies *et al.* (1978) used high-voltage electric grids to screen suction trap (22·9-cm diameter) sunk into the ground to study low level mosquito flight in response to wind direction. These electrocuting grids, which are very similar to those designed to study tsetse flies (Vale, 1974), could be used with other sampling methods and so are described here.

Steel wires (0·15 mm) 5 mm apart were tied at one end with nylon thread and tensioned at the opposite end with a steel spring to 44-cm wide and 46-cm high aluminium frames. A step-up transformer, as used in commercial electrocuting fly traps, boosted the voltage from a 240-V a.c. generator to about 5000 V a.c. A series of resistors inserted into the primary circuit reduced the input voltage until there was no spontaneous sparking in the grid; the working output voltage was then about 2000 V. A switch was inserted in the circuit to bypass these resistors so that when the trap was switched on sparking showed it to be working, after which the switch was operated. The authors believed that the current was about 1 mA, which is harmless to accidental human contact, but either knocks down or burns up mosquitoes hitting the wires. Apparently the electrocuting grid killed 75–80% of the insects attempting to fly through it. In later experiments (Gillies & Wilkes, 1981) to help prevent mosquitoes passing through the screen a second grid of wires 3 mm apart, but not electrified, was placed behind the live grid. A problem that may arise is that some of the electrocuted insects may be so damaged that they are difficult to identify to species (Gillies & Wilkes, 1981).

The following equations (Gillies *et al.*, 1978) show the effect of grid efficiency (75–80%) on the relationship between the true proportion of mosquitoes flying upwind (a) and the estimated proportion flying upwind (x).

$$x = \frac{a(1 - Z_d) + Z_d}{1 + Z_d + a(Z_u - Z_d)} \quad \text{and} \quad a = \frac{x(1 + Z_d) - Z_d}{1 - Z_d - x(Z_u - Z_d)}$$

where Z_d = proportion of downwind flying mosquitoes passing through the grid, and Z_u = proportion of upwind flying mosquitoes passing through the grid. It is reasonable to assume that $Z_d = Z_u$, so using just Z the equations simplify to

$$x = \frac{a(1 - Z) + Z}{1 + Z} \quad \text{and} \quad a = \frac{x(1 + Z) - Z}{1 - Z}$$

From the above equations it can be calculated that with a grid efficiency of 75–80% (Z = 0·2–0·25), a total catch of say 64% (x) in traps facing downwind would indicate that 72–73% of the mosquitoes were in reality flying upwind (a).

Vertical distribution

Ecological studies in wooded areas in England clearly showed that the densities of unfed *Aedes cantans* and female *Culex pipiens* with fat reserves (Service, 1971*a*) and *Culicoides* species (Service, 1971*b*) decreased rapidly with small increases in height (23–550 cm) (Fig. 4.10). It seemed likely that this was correlated with low level flights for host seeking and oviposition. This assumption was supported by the discovery that during the gonactive season *Culex pipiens*, an ornithophagic species, was commonest in the highest suction trap (550 cm), but when blood-feeding stopped and females sought hibernation sites adults were commonest in the lowest traps.

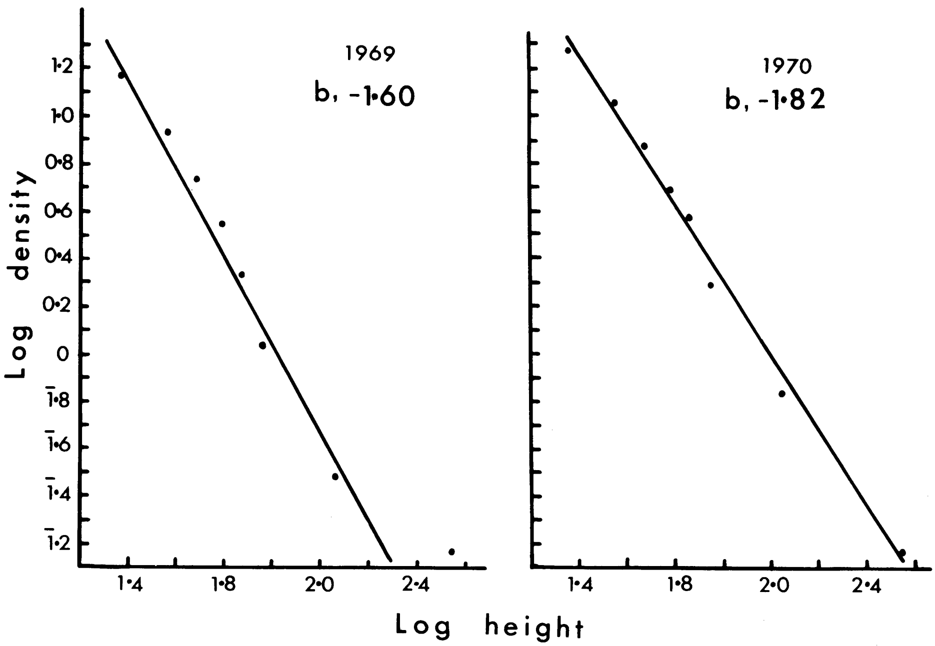

FIG. 4.10. Log height × log density profile of unfed Aedes cantans *caught in suction traps at different heights (after Service, 1971a).*

Snow (1975) initiated studies in The Gambia on the vertical distribution of mosquitoes. In a coastal region he used 22·9-cm diameter 'Vent-Axia' suction traps positioned at heights of 0·68–9·15 m on short and taller scaffolding towers; ramp traps were also used. The commonest species trapped were *Anopheles melas* and *Culex thalassius*. Later Gillies & Wilkes (1976) studied the vertical distribution of mosquitoes in a savanna area of The Gambia, employing suction traps at heights of 0·5–6·0 m (Fig. 4.11). Three main patterns of flight behaviour were recognised, namely: (1) species such as *Mansonia uniformis* and *Mansonia africana* (not separated), *Aedes* spp. and *Anopheles pharoensis* and *Anopheles ziemanni* which mostly fly below 1 m; (2) species such as *Anopheles funestus, Anopheles gambiae* and *Culex neavei* with flight levels more or less evenly distributed near the ground, but decreasing above 2–4 m; and (3) the high-fliers comprising *Culex antennatus, Culex thalassius* and *Culex poicilipes* with densities at 6 m greater or much greater than at 1 m, (Fig. 4.12). In a final series of observations on vertical distribution of Gambian mosquitoes Snow (1982) placed suction traps at heights of 0·1, 0·25, 0·5, 1·0, 2·1, 3·9 and 7·9 m in savanna areas near a swamp and near a village. Their vertical distribution was categorised into four main groups: (1) species whose densities progressively decreased with increasing height, e.g. *Anopheles*, *Aedes* and *Mansonia (Mansonioides)*; (2) species such as *Culex thalassius* whose densities increased to heights of 0·5 or 1 m, then decreased; (3) species such as *Culex poicilipes* and *Culex weschei* which were most common in the highest trap (7·9 m); and (4) some uncommon species such

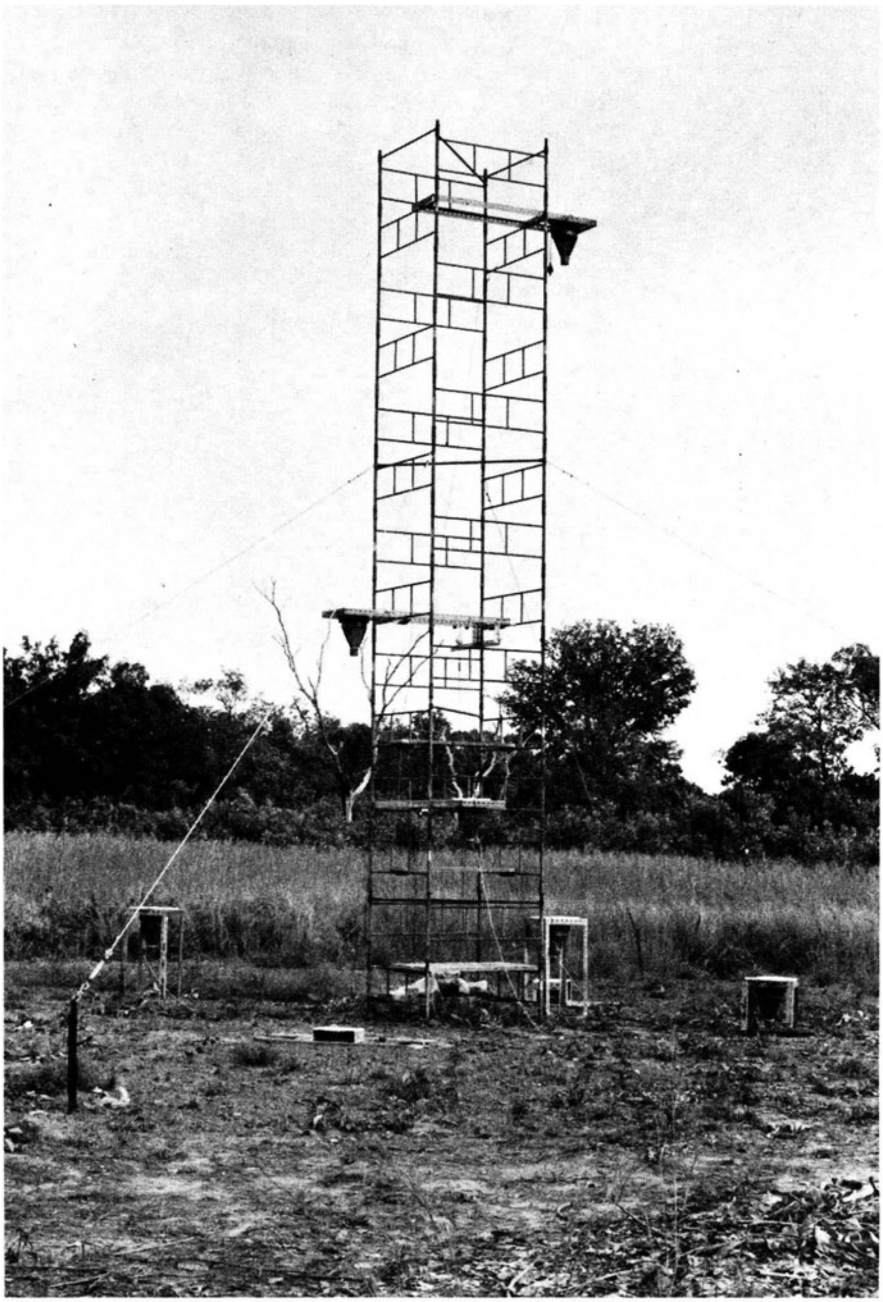

FIG. 4.11. Scaffold tower in The Gambia with Vent-Axia-type suction traps at different heights (photograph courtesy of W. F. Snow).

as *Culex neavei* that appeared to be common at all heights. This, however, is a simplified summary because within a species flight levels sometimes differed according to sex and the gonotrophic state of the females. Moreover there was an increase in the proportion of mosquitoes taken in the lowest trap (inlet at ground level) during the latter part of the night (2300–0500 hr) (Gillies & Wilkes, 1976; Snow, 1982). Snow (1982) thought that such changes in flight levels might have been associated with falling ambient temperature.

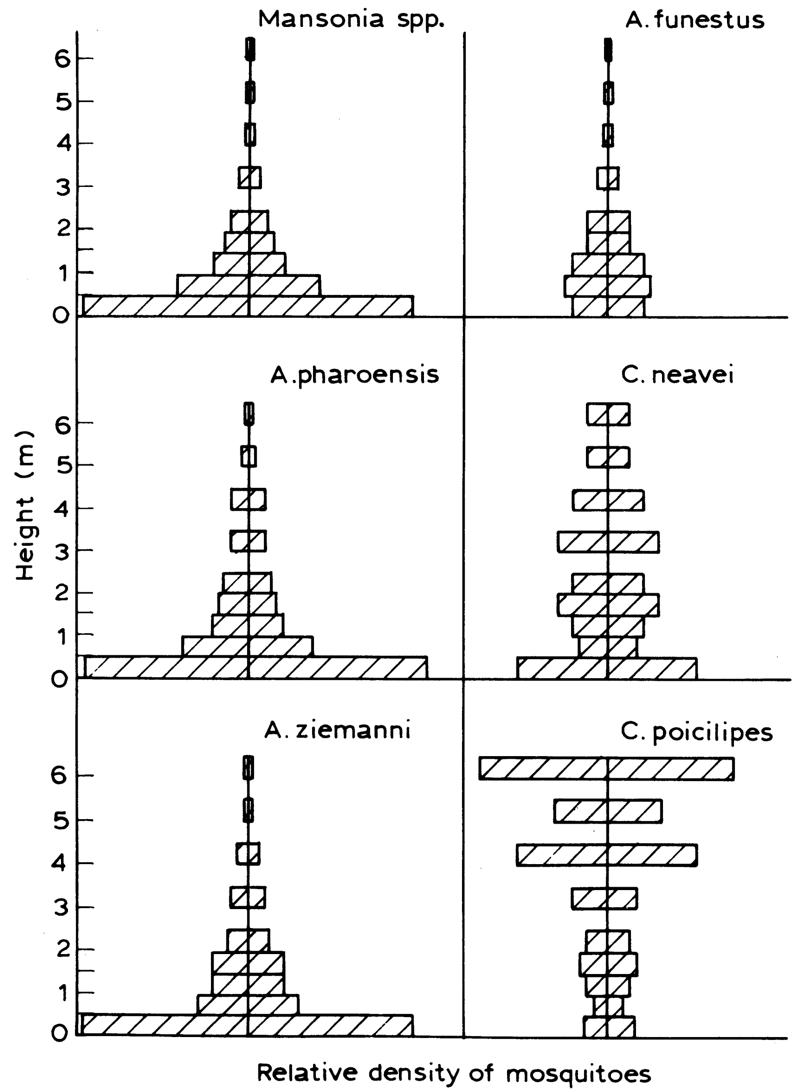

FIG. 4.12. Vertical distribution of six species, or groups, of mosquitoes over open farmland showing low-flying species on the left, and intermediate and high-level species on the right (Gillies & Wilkes, 1976).

In most of the above trials, the positions of the traps were changed after each night's catch to avoid bias caused by variations in their efficiencies. The distribution of mosquitoes in the air will be determined in part by their selection of their own flight level. When, however, wind speed is greater than their flight speed they will have less control over their flight, and some will be swept into the upper air. Species breeding in exposed areas are more likely to be subjected to wind dispersal than those in sheltered sites, such as woods. Glick (1939) recorded mosquitoes up to 1 530 m, and *Culex tarsalis* has been caught at 610 m (Glick & Noble, 1961). In the tropics some nocturnal sylvan species both swarm and feed high up in the forest canopy, but because air turbulence and convection is usually at a minimum during the night, night flying insects are less likely to be affected by air current than day fliers.

In studying the distribution of insects at low levels Taylor (1960) concluded that the density of most small insects decreased markedly with increasing height but larger insects tended to select their own flight levels. This seems to be the case with *Chrysops caecutiens*, which showed no general decrease in density with increasing height, but a definite flight level was selected, below and above which the population was smaller (Service, 1973*a*). Taylor (1958) introduced the term 'boundary layer' to describe a hypothetical layer of air near the ground within which insects could control their flight because this was greater than the wind speed. Above the boundary layer the type of flight will depend largely on the degree of protection provided by vegetation. Further evidence of the existence of a boundary layer was given by Taylor (1974).

Johnson (1957) found that the diminishing density of insects with height could be fitted to the emperical equation:

$$f(z) = C(z + z_e)^{-\lambda}$$

where $f(z)$ = density at height z, λ = an index of the gradient of density on height, C = a scale factor or constant related to population size and z_e = a constant, which is a measure of the departure from linearity of the curve obtained by plotting log values of aerial density against log height.

Total aerial population

In estimating the total aerial population of mosquitoes between any two heights the first step is to plot log density ($\log f(z)$) against log heights ($\log z$) and obtain a curvilinear graph (Fig. 4.13). Then by trial and error a constant (z_e) is found which when added to each of the values of the heights (z) converts the curve to a straight line when $\log (z + z_e)$ is plotted against $\log f(z)$. The densities of the mosquitoes (fz_1, fz_2) are then read off the graph at two heights (z_1, z_2) near the ends of the plotted line, and the value of λ (the regression coefficient) can be calculated from the following formula:

$$\lambda = \log \frac{(fz_1)}{(fz_2)} \div \log \frac{(z_2 + z_e)}{(z_1 + z_e)}$$

Alternatively the value of λ can be calculated by normal regression methods.

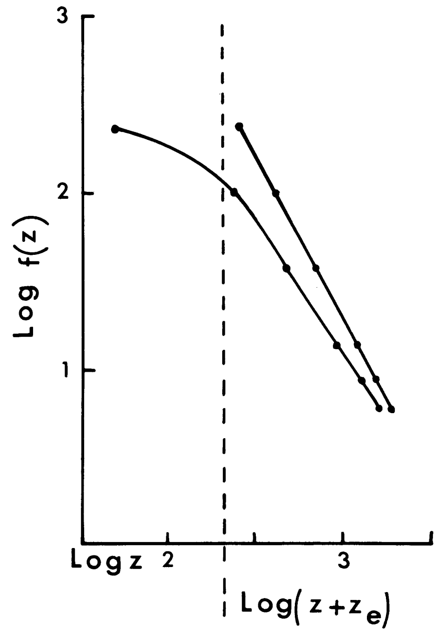

FIG. 4.13. Log density (f(z)) of insect catch in suction trap plotted against log height (z) to give curvilinear plot. A constant value (z_e) is then added to each height to produce a straight line (after Johnson, 1957).

The value of C can be obtained from the following equation:

$$\log C = \log f(z) + \lambda \log (z + z_e)$$

Having calculated the values of Z_e, λ and C, then the number of mosquitoes (P) estimated to be dispersed in a column of air between any two heights (z_1, z_2), is obtained by integrating density on height (i.e. $f(z) = C(z + z_e)^{-\lambda}$):

$$P = \frac{C}{1 - \lambda} [(z_2 + z_e)^{1-\lambda} - (z_1 + z_e)^{1-\lambda}]$$

Less accurate, but nevertheless good, approximations of the total population of mosquitoes between two heights can be obtained from simple graphical methods (Johnson *et al.*, 1962). The first step is to plot log densities of mosquitoes against log heights, and to read off from the visually fitted curve density estimates at various selected heights. These values are then plotted against heights on arithmetic graph paper and the area under the curve represents the estimated total population of mosquitoes.

Suction trap of Bidlingmayer

This differs from the traps developed by Johnson and Taylor in having the fan mounted on its side not vertically. The body of the trap is made of plywood over a wooden frame and is shaped like the letter 'L' lying on its side (Fig. 4.14).

FIG. 4.14. Example of a typical L-shaped suction trap of Bidlingmayer (1974) (M. W. Service).

At the distal end of the section lying horizontal to the ground is a 24-in diameter ¼-h.p. fan with a displacement of about 216 000 ft^3 air/hr. The intake of the trap which measures 31 × 31 in is situated 5 ft above the ground at the top of the short vertical section. Air drawn through the intake passes through a large mesh cone and is discharged through a metal tube attached at right angles to the cone. A cloth bag is fitted to the end of this metal tube to retain the mosquitoes, which in this trap do not pass through the fan blades. To prevent rain and debris entering the trap a clear plastic flat roof is positioned about 8 in above the intake (Fig. 4.8*e*).

These traps have been extensively used in Florida by Bidlingmayer to study the flight behaviour of mosquitoes in relation to topography and meteorological conditions (Bidlingmayer, 1964, 1967, 1971, 1974; Bidlingmayer & Evans, 1987; Bidlingmayer & Hem, 1979, 1980; Bidlingmayer *et al.*, 1985). In a brief redescription of the trap Bidlingmayer & Hem (1979) gave the same measurements as detailed originally by Bidlingmayer (1964), but in metric, and stated that it sampled 102 m^2 air/min (velocity = 2·74 m/s). Measurements made at 5 cm above and horizontal to the edge of the trap's entrance showed that in still air velocities were 347, 238, 145, 60 and 25 cm/s at distances of 0, 10, 20, 30 and 40 cm, respectively.

Now laboratory experiments with *Aedes* and *Culex* species have shown that their flight speeds are in the range of 150–250 cm/s, so up to 10 cm from the trap virtually all mosquitoes will be caught. If a species is attracted visually to the trap to within 30 cm or less, a large proportion would be caught, but if another species passed by at distances greater than 30 cm, few or none would be caught.

Employing traps which were somewhat similar to Bidlingmayer's trap, Dow & Gerrish (1970) found that day-to-day differences in the catch size of *Culex nigripalpus*, but not *Aedes taeniorhynchus*, were significantly positively correlated with day-to-day differences in relative humidities measured 1 hr after sunset. This paper is particularly interesting because the authors, guided by professor W. G. Cochran, have recognised some of the problems of dealing with abnormally distributed data.

Bidlingmayer & Evans (1985) describe a time interval sampler that can divide the catch from Bidlingmayer-type suction traps into 27 samples. It consists of two concentric acrylic plastic cylinders (6, 10), about 15 in high (Fig. 4.15). The inner cylinder (6) is mounted around a central stainless steel helix screw (20) and

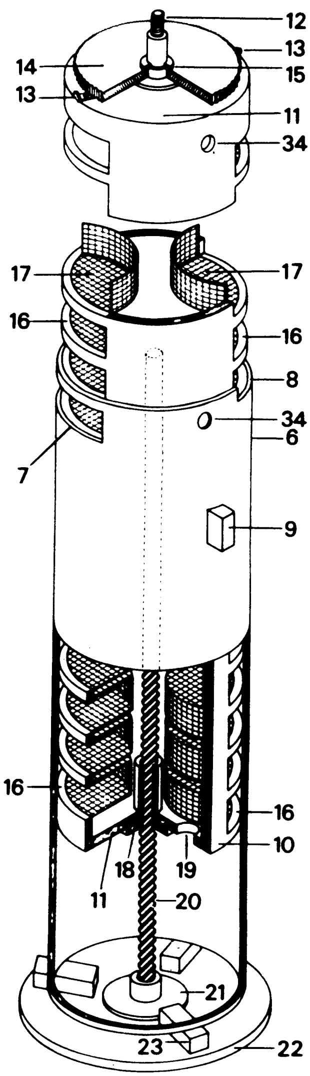

FIG. 4.15. Cylinder assembly of telescopic collection chamber for suction traps and other traps: 6 — outer cylinder, 7 — inlet port, 8 — notch, 9 — key, 10 — inner cylinder, 11 — end plates, 12 — upper spindle, 13 — eared tabs, 14 — gear, 15 — washer, 16 — cup openings, 17 — collecting cups, 18 — helix nut, 19 — drain holes, 20 — helix screw, 21 — flange, helix screw, 22 — basal disc, 23 — spacer, 34 — locking holes. For full details of other parts see Bidlingmayer & Evans (1985).

contains a stacked series of 14 paired semicircular collection chambers (cups) (17). A motor (115-V, 5-W, 12 rev/min) and drive assembly turns the helix screw and screws the inner cylinder down into the outer one (10), and in so doing positions a cup opposite an entrance port (16) through which the air and insects of the suction trap are blown. The overall height of the cylinder is 32 in. Although this rather complicated device is built to receive insects from a horizontal airstream, the authors point out it could be mounted horizontally to receive a vertical airstream. Moreover, if three cups were positioned at 120° apart on the inner cylinder instead of two at 180° the height could be reduced to just 22 in.

Flight behavioural studies of Bidlingmayer

In Florida using his L-shaped suction traps Bidlingmayer (1975) studied mosquito flight paths of several mosquitoes, in particular *Anopheles crucians, Anopheles quadrimaculatus, Aedes vexans, Coquillettidia perturbans, Culex nigripalpus, Culiseta melanura* and *Psorophora confinnis*. Their response to the visual effects of vertical and horizontal barriers made of mesh netting, placed adjacent to or over the traps, but which had sufficient space for mosquitoes to fly through the mesh holes, was investigated. When traps having vertical netting were placed in an exposed position in a field the catches were larger (1·4–3·9 ×) than catches in similar traps without netting (except in one series where the mean catch of *Aedes vexans* remained the same). In contrast, in a wooded swamp the only species whose catch was significantly increased was *Culiseta melanura* (1·4–1·9 ×), in fact the numbers of *Anopheles crucians* was significantly reduced in traps with netting (0·6–0·8 ×). When horizontal netting was placed over the traps catches were reduced for all species, except that in some trials the numbers of *Culiseta melanura* (1·2 ×) and *Culex salinarius* (1·1 ×) were slightly greater. At full moon the response to both vertical and horizontal netting was substantially reduced, suggesting that the netting may have been perceived at a greater distance and avoiding action taken.

In a wood in England Service (1974) had netting with 3·8-cm diameter openings radiating out for 2 m in three directions from his 'Vent-Axia' suction traps. Catches of all mosquito species (*Aedes cantans, Culex pipiens, Culex torrentium. Anopheles plumbeus, Culiseta morsitans, Aedes geniculatus, Anopheles claviger* and *Coquillettidia richiardii*) were greater in traps with than without netting, but only in the first five species was the increase (1·78–3·34 ×) significant. These results suggest that, at least under certain circumstances, mosquitoes are guided by vertical structures and fly alongside 'barriers'. Differences in behaviour of woodland mosquitoes to vertical barriers reported by Bidlingmayer and Service may be due to differences in the species sampled, and/or differences in vegetative cover in the two woods.

In Florida Bidlingmayer & Hem (1979) found that mosquitoes must approach within 30-cm or less of their suction trap intake to be captured (see p. 331).

Among the 14 species caught, the more common were *Culex nigripalpus, Uranotaenia lowii, Uranotaenia sapphirina, Anopheles crucians. Anopheles atropos, Deinocerites cancer* and *Culiseta melanura.* More adults of all species, except *Aedes sollicitans* (an uncommon species in their area), were collected in traps covered with black panels, than in traps without these panels, but both these traps caught more mosquitoes, except *Uranotaenia lowii*, than an acrylic transparent trap. In other experiments when traps were buried in the ground, some were fitted with 1·2-m high transparent or black extensions so the air intake was at 1·2 m. Other traps had 1·2-m transparent or black baffles mounted on the trap, but with the air intake remaining at ground level. It appeared that increasing trap visibility could either increase or decrease the numbers caught, depending on the behaviour of different species. For example, several species were attracted from some distance to conspicuous objects, but in closing in they avoided them by flying over or round them.

Bidlingmayer (1971) showed some mosquitoes, he called them field species, rest in exposed areas of grassland during the day and feed in these areas at night, in contrast to commuter species which shelter in woods during the day but fly out to seek hosts at night. Finally there are the so-called woodland species that rest and feed primarily in woods. Bidlingmayer & Hem (1979) believed that woodland mosquitoes come nearer (< 30 cm) to objects before avoiding them than do field species. They argued that a larger percentage of woodland species will be captured in suction traps than will field species, and concluded that large suction traps in open habitats cannot be regarded as non-attractant sampling devices. It might be pointed out, however, that the suction traps used by Bidlingmayer are much bigger than the Johnson–Taylor traps or the 'Vent-Axia' traps used in England and The Gambia. Later Bidlingmayer & Hem (1981) showed that field species such as *Psorophora columbiae* and *Psorophora ciliata*, are caught at night in about equal numbers in suction traps sited 11 or 87 m from the edge of a woodland. In contrast woodland species, such as *Aedes vexans, Anopheles crucians, Culiseta melanura* and *Culex nigripalpus*, are caught in reduced numbers in traps sited 87 m from the woods. That is, the population of woodland species declines with increasing distance from the woods. It was suggested that these species may maintain visual contact with the silhouette of the woodland edge.

The effect of nearby traps on catches was investigated by placing 4–20 identical L-shaped traps 15 or 30 m apart in variously spaced configurations in a large open field (Bidlingmayer & Hem, 1980). It was concluded that most species responded visually to traps at approximately 15·5–19 m. *Aedes vexans* and *Psorophora columbiae* responded to traps from the greatest distance, followed by *Culex nigripalpus, Culiseta, melanura, Anopheles crucians, Psorophora ciliata* and *Uranotaenia lowii.* Only *Uranotaenia sapphirina* and *Culex quinquefasciatus* appeared to respond to traps from just 7·5 m or less. The numbers of female mosquitoes caught in a trap decreased on average by 33% with each additional competing trap which acted as a visual target. The ratio of the numbers caught from suction traps surrounded by a group of traps (inside), and traps placed in an outer row (edge), at a corner and beyond a corner are shown in Fig. 4.16. The estimated catch ratio for a trap placed beyond the visual competitiveness of other traps is also shown, and by extrapolating the curve in Fig. 4.16 such a trap would likely catch about five times as many mosquitoes as a trap surrounded by competing traps. To avoid trap interference (i.e. competition between traps) they

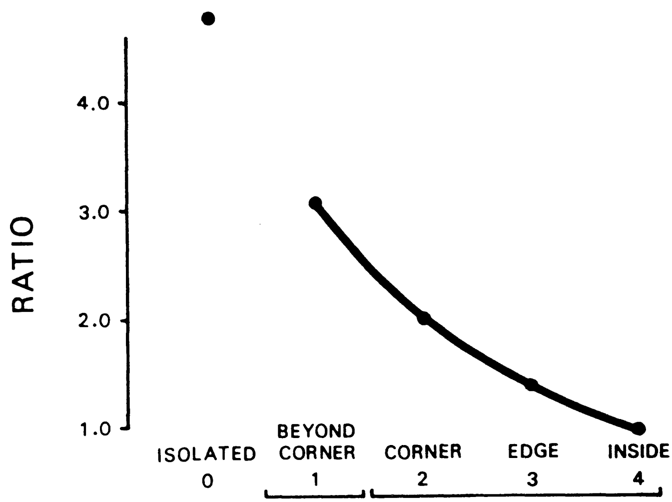

FIG. 4.16. Mean trap catch ratios for female mosquitoes between beyond corner, corner, edge, and the inside traps (inside traps = 1·0) with one, two, three and four adjacent traps, respectively, serving as competing visual attractants. $Y = -1{\cdot}65$ *(log x) + 3·28 = 2·38, 2·14, 1·47 and 0·99, respectively, when x = 1, 2, 3 and 4. The estimated catch ratio for a trap without visual competition is shown also (Bidlingmayer & Hem, 1980).*

should be placed at least 40 m apart. However, the actual distance that different mosquito species perceive objects (traps) varies.

Bidlingmayer & Hem (1980) considered that their L-shaped traps caught more mosquitoes than traps discharging air downwards and outwards (e.g. Johnson–Taylor traps, 'Vent-Axia' traps). This was because the discharge from their traps formed an angle of only 23° with the centre of the trap intake, and they believed that only over this zone would mosquitoes have difficulty in flying to the trap. Furthermore, because the exhaust air is emitted 1·6 m from the trap intake, and mosquitoes are only caught within a 30-cm range of the air intake, they argued that their traps would cause less disturbance to flying mosquitoes than traps discharging air below them horizontally in all directions.

Bidlingmayer (1974) found that the numbers of *Culex nigripalpus* caught in his suction traps decreased by 50% in winds of 0·45–0·89 m/s and by 73% in winds of >0·89 m/s. In Florida when some suction traps were placed on land and others on a raft moored in a water-filled borrow pit 107·5 m from the shoreline, Bidlingmayer *et al.* (1985) found that wind speeds up to 0·24 m/s had no discernable effect on the numbers of *Aedes, Anopheles, Coquillettidia, Culex, Culiseta, Psorophora*, or *Uranotaenia* caught. However, wind speeds of 0·25–0·49 m/s reduced catches of *Culex nigripalpus* and *Culex erraticus* by about 75%, and when wind speeds were about 0·50 m or more/s catches were reduced by 90%. There was no evidence of downwind flight at any velocities. It seemed that high winds greatly reduced the numbers of mosquitoes captured, which is contrary to findings obtained with suction traps in grassland. For further details on the effect of wind and wind shadows on mosquito flight behaviour see Bidlingmayer *et al.* (1985). In The Gambia, Snow (1980), using suction traps, found that host-seeking flights of *Anopheles melas* and *Culex thalassius* did not appreciably decrease until the wind increased to 120 cm/s.

Bidlingmayer & Hem (1980) believed that the catch in a suction trap was dependent on two major factors, namely: (1) the physical features of the surrounding terrain such as natural objects (trees, bushes etc) and artificial objects (other traps) which may visually compete with it; and (2) even slight variations in wind speed. According to them, catches will be most variable when traps are surrounded by many various sized objects in an irregular distribution.

Because of the often quite large day-to-day variations in the numbers of mosquitoes caught by most sampling methods, mainly caused by meteorological conditions, Bidlingmayer (1985) proposed that the percentage increase or decrease in catch size caused by moonlight, temperature, relative humidity and wind speed should be taken into account. He illustrated the approach using collections of *Culex nigripalpus* in suction traps. From regression equations he calculated the increases and decreases of *Culex nigripalpus* in suction traps caused by moonlight and temperature, and more directly the percentage change caused by wind and relative humidities. Using these in simple formulae he derived correction factors for each meteorological factor. For example, for moonlight correction (k), $k=1-(np/1-np)$, where n = days and p = mean percentage change. Then he multiplied trap catches by the product of all the correction factors to give an adjusted trap catch. The validity of this approach has still to be tested in the field for different species and in different weather conditions, before its usefulness can be determined.

In summary, when wind speed is below the mosquito's flight speed mosquitoes generally fly upwind (Gillies *et al.*, 1978; Service, 1980; Snow, 1975), but conspicuous objects can cause mosquitoes to deviate from a strictly upwind flight (Bidlingmayer & Hem, 1980; Snow, 1975, 1976). The silhouette of an object can be discerned at a distance, but as a mosquito approaches the outline and shape of the object is lost (Mazokhin-Porshnyakov & Vishnevskaya in Browne & Bennett, 1981). However, as the closeness of approach to objects differs among species (Bidlingmayer & Hem, 1979), the mosquito's appreciation of the object will differ and they will respond differently when at close quarters (Bidlingmayer & Evans, 1987). In this last paper the authors point out that differences in behaviour at close range (e.g. a metre or less) to visual targets can affect their orientation to hosts, and also the measurement of mosquito populations with traps when visual stimuli play a role. It appears that some species will tend to fly up and over an object while others will fly around it. They consider that trees, shrubs and other barriers may affect feeding patterns, and that physical features in the vicinity of a trap may affect the composition of the catch.

Directional trap of Horsfall

Because stationary nets with vertical openings mainly collect mosquitoes flying with the wind Horsfall (1961) used directionally orientated suction traps to study flight direction. He constructed a group of four suction traps into a single unit. Each trap consisted of an 8-in fan mounted at the top of a 10-in diameter, 18-in long cylinder, which had a copper mesh (14 × 18 meshes/in) collecting cone at the base leading to a small collecting cage. A jointed and elbowed 10-in diameter metal cylinder, with a flared opening 13½ in in diameter at right angles to the fan, was mounted on top of the trap. The openings of the four traps comprising a single unit faced different directions. Horsfall (1961) considered that when an 8-in diameter fan was used insects were drawn into the traps from a distance of up to 6 in from the openings. However, this obviously will depend, among other factors, on wind speed and insect size. Because of the limited distance from which mosquitoes were sucked into the traps Horsfall (1961) considered that those collected were mainly individuals flying towards the traps and consequently directional flight was measured.

Trap construction could be simplified by using flexible tubing (e.g. 'Flexitube') instead of a jointed metal cylinder; alternatively the traps could be positioned on their sides with their openings perpendicular to the ground.

In Indiana Novak *et al.* (1981) modified the Horsfall trap to study the vertical distribution of mosquitoes in a wood. Their trap consisted of a 25·4-cm diameter metal cylinder elbowed at the top and flared to a 58·4-cm diameter intake (Fig. 4·17*a*), which was painted black with contrasting white stripes. A mesh screen funnel leading to a mesh collecting cylinder (14 × 18-mesh) having a removable screen end was positioned within the top of the straight section of tubing. A Dayton duct-type 28-cm diameter fan was mounted near the bottom of the tubing.

Mosquitoes up to 25·4 cm from the intake were sucked into the trap and were not damaged by passing through the fan blades. To position traps at different heights in the wood a lead pellet (70 g) fitted to a spool of 36-kg nylon line was catapulted over a branch capable of supporting the 9-kg trap. The nylon line was then attached to a rope on which a pulley was mounted that allowed traps to be raised and lowered. From 40 days sampling with two such traps 924 mosquitoes of both sexes and belonging to 20 species were caught, the most common being unidentified *Culex* species, *Aedes hendersoni*, and *Anopheles barberi*. These traps were particularly useful in catching *Culex* species and *Anopheles barberi*, because they were rarely collected at human bait. In other collections from five different microhabitats considerable numbers of *Aedes triseriatus* and *Aedes hendersoni* were collected.

Directional trap of Snow

Snow (1977) modified his earlier suction trap (Snow, 1975) into a directional suction trap (Fig. 4.17*c*). Each trap had a 1·2 × 1·2-m entrance with an inclined floor of green plastic netting (Netlon) and sides and roof made of 1-cm mesh plastic netting, dyed dark green to minimise visual contrast. Mosquitoes were thus guided up this funnel-type entrance to a horizontally-mounted 22·9-cm 'Vent-Axia' suction fan. These traps were used to determine the height and direction of flight of Gambian mosquitoes.

Koch et al. *trap*

Koch *et al.* (1977) described and illustrated an inexpensive suction trap having a turntable device for separating catches of biting flies into hourly samples. Basically

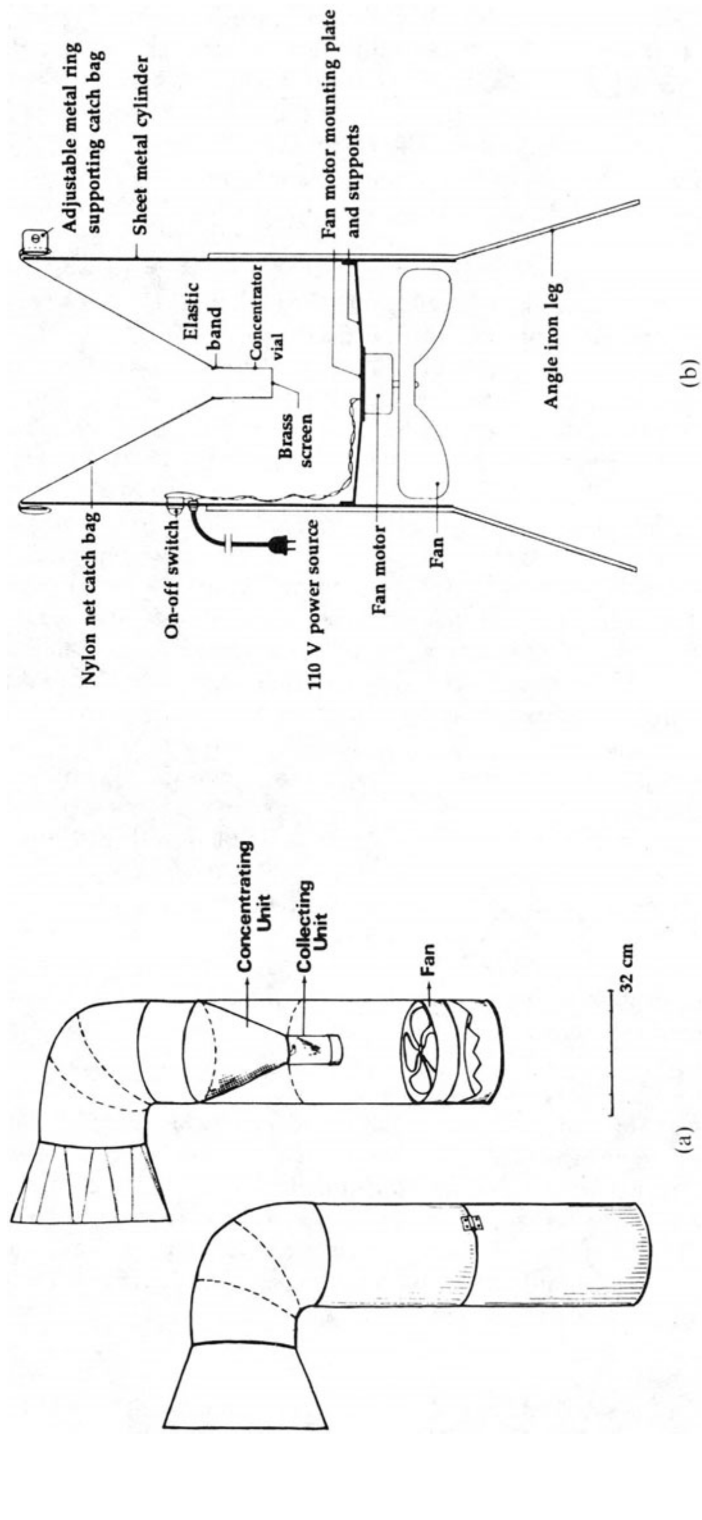

FIG. 4.17. *(a) Directional suction trap (Novak et al., 1981); (b) suction trap of Barnard & Mulla (1977).*

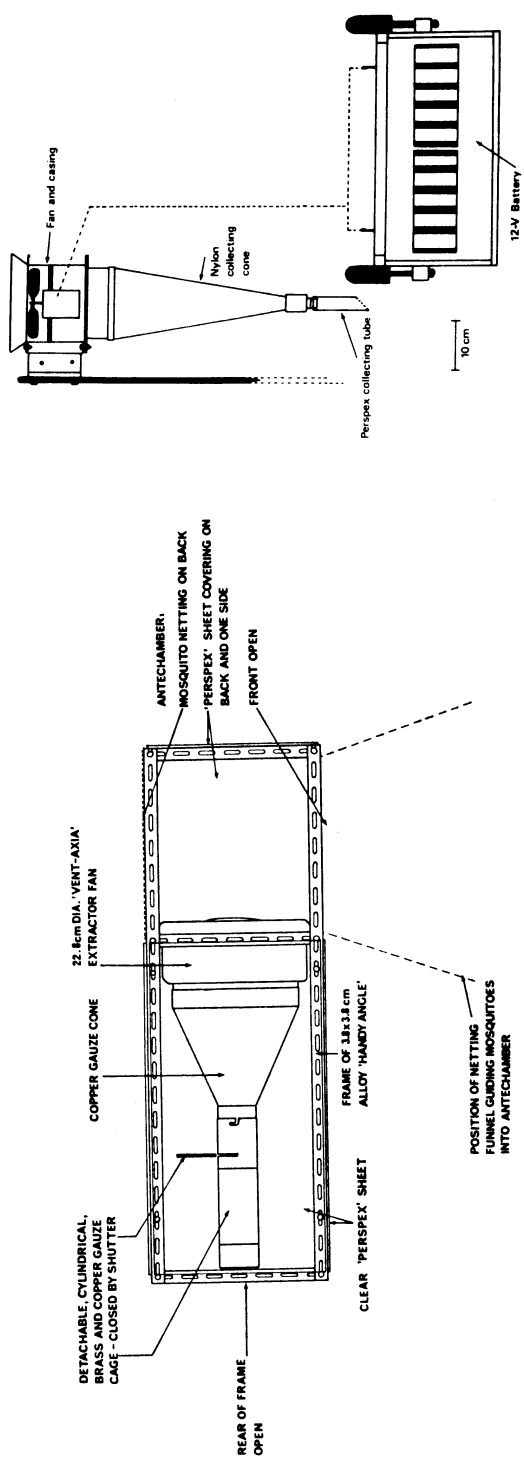

FIG. 4.17—contd. *(c) directional suction trap using Vent-Axia fan (Snow, 1977); (d) battery-operated suction trap (Wainhouse, 1980).*

the trap consists of a 120-V 9-in diameter 6-bladed duct fan attached to a 1/70 h.p. kitchen fan motor, secured in a short length of 12-in diameter metal tubing. A bronze mesh cone underneath delivers the insects to collecting jars fixed under a notched turntable. A 2-lb lead weight tied to a rope advances the turntable when a solenoid causes a timer to close for about 15 s every hour, and this releases a sliding bar (slider-bar) resting against one of the notches in the turntable. This trap is rather similar to the Johnson–Taylor trap (pp. 316–19), but with a different sorting mechanism.

Wainhouse trap

Wainhouse (1980) described a battery-operated suction trap for catching small insects that would also be suitable for mosquitoes. The fan consists of an 'Airmax' type PR-Y4393 in an aluminium casing, 15·2 cm in internal diameter and 12 cm deep. The fan blades are inverted and the wires to the motor brushes switched to reverse the direction of rotation, needed for the arrangement shown in Fig. 4.17*d*. A flared inlet made from a 5-cm strip cut from the top of a 60° plastic funnel is fitted to the top of the fan housing. A 6-cm deep flange bolted to the bottom of the fan casing holds in position a nylon mesh cone tapering to a mesh collecting bag. The trap weighs about 1·6 kg. The fan has a 31-W motor and operates at 2900 rev/min from two 25-Amphr 'Alcad' alkaline batteries connected in parallel, the combined weight of which is about 37 kg. The batteries run the trap for about 16 hr. These batteries can be rapidly recharged, and are less sensitive to overcharging than lead-acid batteries and can be left uncharged for short periods without harm. The volume of air sampled by two traps measured with a Metrovic velometer was 329 and 355 m^3/hr, which is about 60% of the volume sampled by 9-in 'Vent Axia' mains-operated traps (Johnson, 1950*a*).

Barnard & Mulla trap

Barnard & Mulla (1977) constructed an inexpensive and simple suction trap. It consists of a 36-in long and 21-in diameter galvanised metal cylinder supported on three ½-in angle-iron legs, adjusted to position the top of the cylinder 54 in from the ground. A 20-in, 5-bladed fan attached to a 115-V, 2.6-A motor (McGraw-Edison model 7327) is mounted on a metal plate supported by three 1-in wide metal arms in the lower part of the cylinder (Fig. 4.17*b*). The motor sucks air through the trap at the rate of 2600 ft^3/min. A nylon netting cone is pulled over a metal band that is placed over the top of the trap, and a plastic vial with a mesh screen bottom is fixed with an elastic band on to the bottom of the cone. This is removed at the end of each sampling period. In California Barnard & Mulla (1978) used these suction traps, New Jersey light-traps, a D-vac aspirator and diurnal resting boxes for sampling *Culiseta inornata.* The light-trap caught most females, followed by the D-vac, resting boxes and the suction trap.

Lumsden–Goma suction trap

Goma (1965) modified the suction trap developed by Lumsden (1957; 1958; see Chapter 5) for catching mosquitoes attracted to bait animals, by removing the transparent louvres at the sides to allow easier entry of mosquitoes. These modified traps without any bait were placed at ground level and on six platforms at 20-ft intervals on a steel tower in Zika forest, Uganda. From a series of forty 24-hr continuous catches 4151 mosquitoes belonging to 34 species or species groups were caught, of which males only formed 3·5% of the catch. Several *Mansonia* and *Coquillettidia* species and *Aedes apicoargenteus* were sufficiently common for their vertical distributions and hourly flight periodicities to be analysed and plotted.

New Jersey-type suction traps

In Puerto Rico New Jersey light-traps were converted into suction traps for trapping *Aedes aegypti* by painting them black and removing the light bulb and cover. When placed in buildings they caught large numbers of adults of both sexes (Anon, 1979).

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