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Possible Use of the Sterile-Male Technique for Control of *Aedes aegypti*

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A critical review of the information now at hand permits only a cautious optimism about the possibility of controlling or eradicating *Aedes aegypti* (L.) by some aspect of the sterile-male technique. This optimism is based principally on the relative ease with which we can rear *A. aegypti* and our ability to sterilize it in the larval, pupal or adult stage without greatly diminishing its longevity or sexual activity. The obstacles to practical applications of the technique are, however, formidable. All approaches to the sterilization of natural populations of *A. aegypti* are beset with difficulties, and the knowledge, such as it is, of the sexual behaviour of this species in the field does not augur well for control by sterile-male releases. The ability of fertile eggs to survive months of desiccation adds to the difficulty.

Mosquitos, as a group, appear less suited to the sterile-male method than muscoid flies, because of differences in sexual behaviour, and the aedine species appear less suitable than the anophelines or culicines, especially, for control by sterile-male releases, because of the survival of large numbers of eggs, which hatch when flooded by unpredictable rainfalls. Although these characteristics place *A. aegypti* among the species least amenable to control by this approach, research on its control by sterility techniques cannot yet be abandoned; the potential rewards are too great. These techniques, where they can be applied, enable one to use treated insects to seek out and destroy the reproductive capacity of the individuals that cannot be reached with insecticides or other means. As demonstrated with the screw-worm fly *Cochliomyia hominivorax* (Coquerel) (Knipling, 1960), and the melon fly *Dacus cucurbitae* Coquillett (Steiner et al., 1965), these techniques provide weapons that can eradicate susceptible species.

The first investigations on induced sterility for mosquito control were directed towards the use of gamma-radiation to sterilize males for release in the field. Davis et al. (1959) demonstrated that *Anopheles quadrimaculatus* (Say) could be sterilized in the pupal or adult stages, and that irradiated males competed, but not on equal terms, with normal males for normal females. Weidhaas, Schmit & Seabrook (1962) released about 1500 sterilized males per square kilometre per week for 11 months on a small, incompletely isolated island in Lake Okeechobee, Fl., with little effect on the fertility or abundance of the wild females.

The experience with *A. aegypti* is no more promising. McCray, Jensen & Schoof (1961) and Fay, McCray & Kilpatrick (1963) showed that sterilized males were less than normally competitive. Morlan, McCray & Kilpatrick (1962) made field releases of this species at Pensacola, Fla. Sterile males were released in one area from July to November 1960 and from April to October 1961, and in a second area during the latter period only. The numbers of males released ranged from 429 to 5156 per hectare, and the estimated ratio of sterile males to wild males ranged from 25 : 1 to 941 : 1 during the significant part of the experiment. In 1960, there was no conclusive difference between the abundance of larvae of *A. aegypti* in the first test area and in a check area; in 1961 abundance was very low in both the test area and the check area. In the second test area, where releases were first made in 1961, larvae were actually more abundant than in the corresponding check area. In 1960, 25% of the eggs collected in the release area hatched, as against 42% of those collected in the check area, but in 1961 64% of those collected in the second release area hatched, compared with 57% in the check area.

An experiment by Krishnamurthy, Ray & Joshi (1962) demonstrated that the release of irradiated males of *Culex fatigans* Wiedemann resulted in the appearance of considerable numbers of egg-rafts in which the eggs were embryonated but did not hatch. There was no reduction in mosquito abundance, possibly because the numbers released were inadequate.

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The radiomimetic chemicals provide some advantages over radiation in the sterilization of insects for release and, in addition, open the possibility of inducing sterility in a large part of the natural population without the necessity of rearing and releasing large numbers of males. If we could sterilize 95% of the larval population, for example, this would be equivalent to releasing 19 sterile males to every normal male at the optimum times and places. *A. aegypti* is indeed susceptible to sterilization with chemicals in the larval stage. Weidhaas (1962) exposed larvae from the third instar until pupation in water treated with 10 ppm of tepa or apholate; tepa induced 100% sterility in the males and 84% in the females, whereas apholate induced only 93% in the males and 74% in the females. Rai (1964) failed to obtain complete sterility with 15 ppm of apholate applied to larvae in the second instar, possibly because much of the chemosterilant had been degraded by the time the gonads reached the most susceptible stage. Dame & Schmidt (1964) obtained only 36% reduction in fertility when larvae were exposed to 10 ppm of metepa. White (1964) found thiotepa to produce sterility in larvae at concentrations of 2.5 to 5 ppm, but it also caused high mortality at 5 to 10 ppm, and the activity of the compound had abated after 1 hour from the time it was added to the larval medium.

Competitiveness of the sterilized males is, of course, essential to the success of the technique. Dame, Woodard & Ford (1964) found that males from larvae treated with 10 ppm and 25 ppm of tepa were not fully competitive with normal males, as 50 : 50 ratios reduced the hatching rate by only 33% of the normal rate. They also found that, when normal females were mated first to treated males and then to normal males, the hatching rate of their eggs was reduced by about 40%, but when they were mated first to normal males, then to treated males, the hatching rate was normal; in this experiment, however, the "normal" hatching rate was only about 50%, whereas it is usually more than 85%.

It is also important to know whether the induced sterility is permanent or transient. Dame & Ford (1964) caged males that had been sterilized in various ways with 4 successive groups of females so as to determine the permanence of sterilization. The treatments induced 99% to 95% sterility at the first series of matings. Males sterilized with 10 ppm of apholate in the larval stage recovered complete fertility by the fourth series of matings, but those sterilized with 10 ppm of tepa in the larval stage recovered only a small part of their fertility, and those sterilized in the adult stage by contact for 2 hours with residues of 100 mg of tepa per m^2 on a glass surface remained sterile.

The possibility that insects might be able to develop resistance to chemosterilants has not been ignored. Hazard et al. (1964) obtained increased resistance to the sterilizing effects of apholate in two colonies of *A. aegypti* exposed to apholate in the larval stage in each generation.

The adult mosquitos are also susceptible to sterilization, either by feeding or by tarsal contact. Weidhaas et al. (1961) obtained complete sterility in *A. aegypti* when both sexes fed on honey solution containing 0.1% of apholate or 0.5% of tepa (aphoxide). Dame & Schmidt (1964) obtained 96% sterility with 1% of metepa on honey, and more than 99% sterility in adult mosquitos exposed for 4 hours on glass surfaces treated with 100 mg of metepa per m^2. Bertram (1963) obtained 98% to 100% sterility in normally impregnated females exposed for 3 hours on deposits of 200 mg of thiotepa per m^2 on paper surfaces. Some of the females treated with thiotepa remained completely sterile through 4 gonotrophic cycles. Males so treated were completely sterile for a period of 15 days, but by 18 to 28 days after treatment they had regained 10% to 20% of their fertility. This was in contrast to the results obtained with tepa by Dame & Ford (1964) mentioned above.

If chemosterilants should ever be used to control disease vectors, one wonders what effect they might have on the disease organisms. Altman (1963) found that holding *A. aegypti* females on a tepa residue of 100 mg/m^2 either immediately before or after they fed on chicks infected with *Plasmodium gallinaceum* Brumpt caused reductions in the percentage of mosquitos that became infected and the malaria transmission rate. Bertram (1964) reported that filaria parasites, *Brugia patei* (Buckley, Nelson & Heisch) were so severely retarded in their growth in *Aedes togoi* (Theobald) sterilized by exposure to thiotepa residues as to make transmission highly improbable. However, prospects for the use of these compounds against disease organisms seem remote with the materials now at hand.

There is no knowledge of field tests with chemosterilants for the control of *A. aegypti*. Lewallen, Chapman & Wilder (1965) treated isolated desert pools with 75 ppm of apholate for the control of *Culex tarsalis* Coquillett. Three weekly treatments caused the elimination of egg-rafts and young

larvae, but a few fourth-instar larvae remained. Populations had returned to normal 3 weeks after the last treatment.

At the present time, it appears that the prospects for controlling *A. aegypti* with chemosterilants applied to the natural population are not bright and depend largely on the development of safer, more stable and more effective sterilants, of efficient attractants and arrestants and of mating, feeding or oviposition stimulants.

Even if the baits or residues could be exposed safely, the amount of chemosterilant that might be transported to people or beneficial animals by the treated insects must be considered. It does not appear that *A. aegypti* would carry hazardous quantities. Dame & Schmidt (1964) found that *A. aegypti* exposed on glass surfaces treated with 100 mg of radiolabelled metepa per m^2 picked up only 2.5 μg. After 3 days of feeding on 1% of the chemosterilant in honey solution, males contained radioactivity equivalent to 1.7 μg; and females 7.5 μg. Plapp et al. (1962) found that, in *C. tarsalis*, degradation of radiolabelled metepa was complete in 48 hours.

The situation is not hopeless. We are accumulating information on attractants and oviposition and feeding stimulants, but space does not permit discussion of progress along these lines. New types of chemosterilants are being discovered in synthesis and screening programmes. There is currently some interest in hempa (hexamethylphosphoramide), which is less toxic to mammals than the compounds previously mentioned.

Emphasis must be placed on the consideration of the sterility techniques, not as methods mutually exclusive of others, but as methods that may be incorporated, with others, into integrated control programmes. As such, they may well provide the *coup de grâce* for infestations that might otherwise escape eradication.

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