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CAN WE CONTROL MOSQUITOES WITHOUT PESTICIDES? A SUMMARY

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ABSTRACT. Up to now insecticides have remained the main tool for both killing mosquitoes and controlling mosquito-borne diseases, but perhaps we should broaden our horizons by looking at the effectiveness of traps in controlling tsetse flies. The problem is that we have not developed any really efficient mosquito traps, and of course population densities and reproduction rates of mosquitoes are far greater than those of tsetses. To interrupt disease transmission we do not need to eradicate vectors, but must reduce their populations to a critical threshold (breakpoint). Despite much enthusiasm, true biological control agents have not generally proved very effective, especially against floodwater species. Insect growth regulators and insect repellents have their uses but they do not provide any panacea for control. Understanding the ecology of mosquitoes is usually of paramount importance in developing control programs, especially those employing biological agents. We need, for example, to understand the intricacies of density-dependent population regulation, and computer modeling can help us to do this, as well as assist in identifying the most efficient control strategies. We need to promote noninsecticidal control of mosquitoes, but until we have developed more efficient methods, there will continue to be reliance on chemical control.

I consider myself as something of an ecologist and am particularly interested in estimating natural mortalities experienced by mosquito populations and in identifying the causes. However, despite this I have never really been convinced of the practicalities of biological control of mosquitoes (Service 1981, 1983, 1985). For instance, I have always argued that biocontrol of mosquitoes, and most other medically important pests, will be much more difficult to achieve, and more importantly sustain, than insecticidal control. Moreover, in many instances even insecticides have not given good control of pests or resulted in substantial reductions in disease transmission; in fact there have been resurgences of some diseases such as dengue and malaria (Service 1992a). But I have always been hopeful that my antipathy towards biocontrol will prove unfounded. We can consider biological and insecticidal control as the 2 extremes of a broad spectrum of control strategies, and I think that in some situations there may be increasing reliance on source reduction and use of repellents and insect growth regulators (IGRs), that is control methods that fit somewhere in between these 2 extremes. But what have we learned from the previous papers in this symposium?

If we were to consider traps for control we should examine the progress made by tsetse entomologists. It is clear from the presentation of Tony Jordan (1995) that odor-baited visual attraction traps and insecticide-impregnated targets can give good control of tsetse flies. What I find particularly interesting is that although traps were used for control at the beginning of this century, they had to be "reinvented" in the 1970s before their full control potential was realized. Today some 60,000 targets are used in Zimbabwe to control tsetses, and continuing research suggests that tsetses can be controlled by odor-baited, real or artificial, tree stumps (Vale et al. 1994). The odors used are acetone and octenol, both found in host breath, and 3-n-propyl phenol and 4-methyl phenol, components of host urine. All these types of substances have been shown to attract certain mosquito species under certain conditions, although it seems none of these chemicals is very attractive without the addition of carbon dioxide (Kline et al. 1990) and this makes their use in traps to control mosquitoes impractical. Tsetse workers have clearly shown the necessity of understanding the basic behaviorial responses of vectors, and the need to study their response to a single stimulus at a time. However, unlike mosquitoes, tsetses occur at low population densities (1,200–4,500 mi.$^{-2}$) and have very low fecundity, producing only 5–8 offspring during a fly's lifetime, which means that traps need catch only, or targets kill, 1–4% of females/day in order to obtain control. The situation is very different in mosquitoes! Furthermore, we have not managed to develop any efficient traps that show any potential for controlling mosquitoes.

John Mulrennan (1995) has stressed that there can be important differences between the control of mosquitoes when they constitute just a biting nuisance, and their control when they are disease vectors. It may sometimes be easier to reduce pest mosquitoes to an acceptable level than to control vectors whose populations may require considerably greater reductions in size to reach the so-called "critical thresholds" (breakpoints) for the interruption of transmission (Service 1993a). On the other hand, with a disease such as Western equine encephalomyelitis, where human cases usually occur only when populations of *Culex tarsalis* Coq. are very large, it may prove easier to reduce populations below the critical disease threshold than to reduce them to an acceptable pest level. With epidemics, such as dengue, there is really no alternative other than to go for catastrophic control that will immediately greatly reduce vector populations and this can be achieved only with insecticides. But just as there are critical vector densities required for a reduction in disease transmission, nonvector densities may need to be reduced to very low thresholds before the public will perceive that control is working. Such levels may be difficult to achieve and sustain without insecticides.

John Beidler (1995) presented the perspectives and problems of a director of a mosquito control district. He considers that no biocontrol strategies can control floodwater mosquitoes such as *Aedes vexans* (Meigen) and *Aedes taeniorhynchus* (Wied.), which are often characterized by rapid and large explosive population outbreaks. He believes, however, that fish may be useful in controlling mosquitoes such as *Culex nigripalpus* Theobald and *Anopheles* species that breed in more permanent waters where populations increase more slowly. Although I appreciate that fish can be voracious predators of mosquito larvae, there is little documented evidence that fish can appreciably reduce adult biting densities, and this must be the objective, not just a reduction in larval population size that will not necessarily lead to reduced adult populations. Moreover, it will likely be even more difficult for fish, or any other predators or parasites, to cause a reduction in disease transmission (Service 1990, 1992b).

Brian Federici (1995) points out that for mosquito control, microbial insecticides such as *Bacillus thuringiensis* ssp. *israelensis* and *Bacillus sphaericus* will mainly be used by the developed world where control has for long focused on larviciding. In integrated pest management programs it may be possible to reduce the numbers of applications against multivoltine species by as much as 50–70%. This is because nontarget organisms, including predators, are not killed by these bacteria, thus letting them continue to contribute to larval mortality. High levels of resistance have been recorded in a few Lepidoptera to other subspecies of *Bacillus thuringiensis* (McGaughey 1990, Tabashnik 1994) so it is conceivable that mosquitoes could develop resistance to *B.t.i.*, although at present there is little evidence of this posing a serious problem (Tabashnik 1994). However, we are told that if this were to happen molecular geneticists using recombinant techniques may be able to overcome any such problems.

Mir Mulla (1995) has spoken about insect growth regulators (IGRs) (methoprene [Altosid]; diflurobenzuron [Dimilin]). One of their advantages is that they kill late in the mosquito's aquatic life cycle, thus minimizing density-dependent counter measures, a problem that arises with some biological control approaches. Furthermore, delaying mortality until the 4th larval instar or pupal stage leaves mosquito larvae and pupae as food for various aquatic fauna, including fishes and wildfowl, which is a bonus for conservationists. The IGRs are generally regarded as ecologically safe although they do kill some aquatic crustacea (Ali and Mulla 1978). Although IGRs can drastically reduce *Cyclops* numbers, some species of which prey on mosquito eggs and young larvae, they can extend larval life, thus favoring the completion of the parasitic stages of *Romanomermis culicivorax* in mosquito larvae, and so allow parasite populations to persist (Service 1992b). Despite posing very little damage to the environment very few new compounds have arrived on the market since the introduction of methoprene for mosquito control in 1974.

Roger Grothaus has stressed that despite recent adverse publicity (Anonymous 1989), deet, which was introduced in the 1950s, remains one of the safest, cheapest, and most effective insect repellents ever marketed (Osimitz and Grothaus 1995), and will likely remain so despite predictions that 2–3 new repellents will be in the shops within the next 4–6 years. Repellents will undoubtedly continue to remain useful as a personal protection method against mosquitoes and other biting arthropods. However, although they can be impregnated into clothing to reduce the risks of people, such as the military, becoming infected with vector-borne diseases, they are unlikely to be incorporated in vector control programs.

Jan Washburn (1995) has highlighted some of the ecological problems facing biological control of mosquitoes. Many good ecological studies on larval population have concentrated on container-breeding mosquitoes because it is easier to census and track their populations than those of species breeding in biologically more complex ground waters, despite the fact that many of the most important vectors colonize such ground water habitats. On the other hand, because of the specialized and temporary nature of containers, whether phytotelmata or water-storage pots, it will be more difficult to "biocontrol" container breeders than mosquitoes found in ground waters.

A very important aspect of vector control is understanding density-dependent population regulation, which may hinder effective biological control (leaving aside microbial insecticides and IGRs) due to feedback into the biological system; leading to reduced larval mortality in the face of introduced parasites and predators. For example, if a biological control agent kills the younger larval instars in preference to the older ones, the resulting reduced densities of older larvae may lessen interspecific competition, for example for food, thus allowing more larvae to pupate and give rise to adults. It follows that natural enemies that concentrate on killing older larvae, or pupae, are more desirable. It is important to recognize that we need to add to natural mortality not compete with it, or replace it. Biological control demands much greater ecological information on the target pests and the enemies being introduced than does insecticidal control. Another problem with many biological control measures is that it is difficult to predict their outcomes, whereas with efficient applications and in the absence of insecticide resistance the outcome of insecticidal control should be predictable.

Fred Roberts (1995) has tried to simplify the mystique surrounding computer modeling and show how it can be used for practical purposes of mosquito control. He argues that using systems modeling can focus pesticide applications on areas where they are most needed, and this should lead to reductions in insecticide use. For example, modeling has clearly shown that in the West African Onchocerciasis Control Programme (OCP), under certain conditions rivers need not be dosed with insecticides every week, as presently practiced, but only every 10–14 days (Birley and Davies 1984). Although this would save money such recommendations have not been adopted because it is believed there would be organizational problems in changing from a weekly schedule, where set tasks are done on the same day each week, to a schedule in which spraying is repeated on different weekdays (Service 1993a).

So, in conclusion, what of the future? Undoubtedly environmental management can sometimes mitigate mosquito nuisances. For example, care in the planning of development schemes such as dams and irrigation projects can reduce, or even sometimes prevent, vector problems, such as by minimizing the creation of mosquito larval habitats. However, it has to be admitted that despite numerous desk studies and lip service, many, if not most, agricultural development projects continue to create health problems (Service 1991). Similarly peoples' behavior and attitudes can, at least in theory, reduce domestic breeding of some mosquitoes, for example *Aedes aegypti* (Linn.), but we all know the poor track record of such a community approach (Service 1993b).

As John Beidler (1995) pointed out, we need to encourage research into the biological control of mosquitoes for a variety of reasons, including insecticide resistance problems, insecticide registration problems, and environmental contamination problems, as well as the likely increasing pressure from the environmental lobby. But, unfortunately, I cannot see any promising breakthrough on the horizon, and so am forced to conclude that pesticides will continue to play a dominant role in vector control in the foreseeable future. However, in many instances we have the information, or can get it, for minimizing pesticide application rates without reducing their control effectiveness. Whenever possible we should also try and time pesticide applications late in the mosquito life cycle so that natural mortalities can take their toll. For example, overwintering populations of mosquitoes should be allowed to reach the 4th instar, thus allowing natural mortalities to occur unhindered, with spraying done later in the season to kill the survivors before they pupate.

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