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Progress in malaria vector control*

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Malaria control, except in tropical Africa, will probably continue to be based to a large extent on the use of insecticides for many years. However, the development of resistance to insecticides in the vectors has caused serious difficulties and it is necessary to change the strategy of insecticide use to maximize their efficacy. A thorough knowledge of the ecology and behaviour of each vector species is required before the control strategy can be adapted to different epidemiological situations. The behavioural differences between sibling species have been recognized for several years, but study of this problem has recently been simplified by improved means of identification that involve chromosomal banding patterns and electrophoretic analysis. Behavioural differences have also been associated with certain chromosomal rearrangements.

New records of insecticide resistance among anophelines continue to appear and the impact of this on antimalaria operations has been seriously felt in Central America (multi-resistance in Anopheles albimanus*), Turkey (*A. sacharovi*), India and several Asian countries (*A. culicifacies *and* A. stephensi*), and some other countries. Work continues on the screening and testing of newer insecticides that can be used as alternatives, but DDT, malathion, temephos, fenitrothion, and propoxur continue to be used as the main insecticides in many malaria control projects. The search for simpler and innovative approaches to insecticide application also continues.*

Biological control of vectors is receiving increased attention, as it could become an important component of integrated vector control strategies, and most progress has been made with the spore-forming bacterium, serotype H-14 of Bacillus thuringiensis. *Larvivorous fish such as* Gambusia *spp. and* Poecilia *spp. continue to be used in some programmes.*

Application of environmental management measures, such as source reduction, source elimination, flushing of drainage and irrigation channels, and intermittent irrigation have been re-examined and currently a great deal of interest is being shown in these approaches.

There has been limited interest in the genetic control of mosquitos and the phenomenon of refractoriness in some strains of the disease vectors, with the idea of replacing the vector species with the refractory strain. More research is needed before this approach can become a practical tool.

It is apparent that in future a more integrated approach will have to be used for vector control within the context of antimalaria programmes. Training of staff, research, and cooperation at all levels will be an essential requirement for this approach.

Except in tropical Africa, malaria control in the years to come will most probably still be based to a large extent on the use of insecticides. However, the slow but steady development of insecticide resistance among malaria vectors may prevent the long-term control of malaria transmission by this method alone. Changes in the strategy of insecticide use will therefore be needed to slow down the development of resistance, and in order to make the best use of the available insecticides it will be necessary to use them in

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conjunction with other vector and parasite control methods, taking into account the local epidemiology of the disease and prevailing socioeconomic conditions.

REVIEW OF RECENT RESEARCH

With the change of the objective of many antimalaria programmes from one of eradication to one of control and with the introduction of a more flexible approach, studies on vector biology, ecology, and behaviour have become the object of renewed interest, although lack of suitably trained entomologists in many endemic areas make their realization difficult.

Vector feeding and resting habits

The efficiency of indoor residual spraying depends, among other things, on the feeding and resting habits of the vector. Insufficient pre-spray information is available to enable us to determine whether the exophily and exophagy observed amongst certain vector species are inherent or induced by insecticide spraying. However, changes in the house-entry pattern, a shift to outdoor biting to avoid insecticide treated surfaces, and exophilic and exophagic tendencies have been reported in *Anopheles farauti* in the British Solomon Islands, *A. balabacensis*[a] and *A. minimus* in Thailand, *A. balabacensis* in Bangladesh, and *A. philippinensis* in India.

Changes in the environment, with or without the use of residual insecticide application, have also been shown to alter the ecology of various vector species. For example, urbanization, development activities, and insecticide use have led to a decline in the density of *A. culicifacies* in Pattukotai in India, whereas other studies have shown that near Delhi, following the incorporation of the riverine belt and other irrigated areas within the growing city, the importance of this species has increased. *A. stephensi* has assumed a particular importance in areas where water storage is carried out in tanks and wells, and, although essentially endophilic, this species was found to rest outdoors in southern Iran and southern India. Exophily has also been recorded in *A. d'thali* in Iran.

In Afghanistan, agricultural development led to the replacement of *A. pulcherrimus*, an established vector, by *A. hyrcanus*, which was found to be resistant to DDT and also exophilic and exophagic. Other studies in Afghanistan have shown that *A. pulcherrimus* exhibits partial exophily and avoids treated surfaces.

Observations in Kisumu, Kenya, revealed that before spraying with the residual insecticide fenitrothion, *A. gambiae* was the dominant species and was more endophilic than *A. arabiensis*, although the two species did not differ in infectivity and host preferences. After spraying, the density of both species was reduced, but there were increases in both the degree of exophily and the relative proportion of *A. arabiensis*. In the same area of Kenya, the exophilic and zoophilic tendencies of *A. arabiensis* as compared with *A. gambiae* have been shown to result in lowered sporozoite rates in the former species.[b] In Ethiopia, *A. gambiae* s.l. and *A. funestus* have been shown to be partially exophilic and *A. pharoensis* and *A. nili* were strongly exophilic. A correlation between the value of spiracular index and environmental humidity was regarded as a basis for the tolerance of *A. funestus* to dry conditions, the intermediate status of *A. gambiae*, and the hygrophily of

[a] Recently *A. dirus* has been identified indicating that this is in fact a species complex. See, PEYTON, E. L. & HARRISON, B. A. *Anopheles (Cellia) dirus*, a new species of the Leucosphyrus group from Thailand (Diptera: Culicidae). *Mosquito systematics*, **11**: 40-52 (1979).

[b] HIGHTON, R. B. ET AL. Studies on the sibling species *Anopheles gambiae* Giles and *Anopheles arabiensis* Patton (Diptera/Culicidae) in the Kisumu area, Kenya. *Bulletin of entomological research*, **69**: 43-53 (1979).

A. pharoensis.[c] The governing influence of humidity on the resting habits was supported by the evidence that in both *A. gambiae* and *A. arabiensis* chromosomal rearrangements governed adaptation to the ambient humidity. Populations exhibiting chromosomal rearrangements favouring a drier environment rested indoors (with a higher saturation deficit during the night than outdoors), while those with arrangements adapted to relatively more humid conditions rested outdoors. The influence of humidity on resting habits probably also explains the frequent movement and high turnover among the indoor resting *A. gambiae* s.l. and *A. funestus* observed in an unsprayed village in Nigeria.

ABO blood groups have been used as markers for mosquito biting studies and it was found in southern Gambia that women received over seven times as many *A. gambiae* s.l. bites as did children. In another study, near Brazzaville, it was shown that the number of *A. gambiae* s.s. bites on infants, children, adolescents, and adults were in the proportions of 1:2:2.5:3 and thus that there was again an age-related biting pattern.

Precipitin analysis of anopheline blood-meal samples has also yielded valuable information on host preferences.[d] Data on *A. funestus* confirm its highly endophilic and anthropophilic habits. In Jirima, Nigeria, the mean human blood index was found to be 0.92 in *A. gambiae* and 0.50 in *A. arabiensis*. When few animals were present during sampling in Bendel State, Nigeria, both species fed exclusively on man. In Kenya, the proportion of man-fed mosquitos was higher in *A. gambiae* s.l. than in *A. arabiensis*. In Indonesia, the proportion of man-fed *A. aconitus* was lower in treated houses than in unsprayed outdoor biotypes.

A. aconitus in Central Java, Indonesia, was found mostly resting outdoors and the endophilic fraction rested only on the lower parts of walls so that effective control could be achieved by selective spraying of the lower portion of the walls only.

Species complexes and vector genetics

Specific identification of the mosquito is important not only for fundamental biological studies but also for control programmes since some species are vectors of disease and the others are not. Many species display considerable intraspecific morphological variation, rendering their accurate identification difficult. The problem of sibling species in *Anopheles* has been recognized for over half a century, since the first observations on "anophelism without malaria" in Europe, which led to the elucidation of the *A. maculipennis* complex. Now modern techniques of cytotaxonomy and biochemical tests, including enzyme electrophoresis and serological tests, are used to determine species complexes and to identify the individual species. Among the *Anopheles* species complexes, conventional morphological methods have been utilized for the *A. annularis*, *A. barbirostris*, *A. funestus*, *A. hyrcanus*, *A. leucosphyrus*, *A. maculipennis*, *A. minimus*, *A. subpictus*, and *A. umbrosus* complexes, but taxonomic characters alone have proved to be insufficient for members of the *A. gambiae* complex.

The six species now recognized in the *A. gambiae* complex (*A. arabiensis*, *A. gambiae*, *A. melas*, *A. merus*, *A. quadriannulatus*, and species D—a provisional name) were first detected because of their crossing characteristics and subsequently confirmed by studies on chromosome morphology. Intensive polytene chromosome studies in Nigeria helped to elucidate the behavioural divergencies between *A. gambiae* and *A. arabiensis*, the two most anthropophilic and efficient vector species of the complex.[e] *A. gambiae* predominates in

[c] VINOGRADSKAJA, O. N. & DETINOVA, T. S. The value of the spiracular index as an indication of hygrophily and xeroresistance of *Anopheles* mosquitos. Communication I. Mosquitos of Africa. *Medicinskaja parazitologija i parazitarnyie bolezni*, 47: 40-45 (1978).

[d] GARRETT-JONES, C. ET AL. Feeding habits of anophelines (Diptera: Culicidae) in 1971-78, with reference to the human blood index: a review. *Bulletin of entomological research*, 70: 165-185 (1980).

[e] COLUZZI, M. ET AL. Chromosomal differentiation and adaptation to human environments in the *Anopheles gambiae* complex. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 73: 483-497 (1979).

the forest and humid savanna while *A. arabiensis* is more prevalent in savanna and steppe. However, both are capable of colonizing the contrasting environments of typical rain forest and sahel savanna owing to a remarkably high degree of plasticity in chromosomal arrangements relating to microclimatic conditions, particularly humidity, that are influenced by man (e.g., dry-season breeding grounds through irrigation or deforestation; and urbanization favouring isolated populations of *A. arabiensis*). However, the cytogenetic technique can be applied only to fully grown larvae or females with Stage IV ovaries. Recent laboratory experiments with *A. stephensi* have demonstrated relationships between a single chromosomal inversion and various biological and morphological characters. This 2Rb inversion was found to affect the time of pupation and adult emergence, egg-size, time of circadian flight activity, frequency of mating with heterospecific males, and feeding.

Electrophoretic techniques based on gene-enzyme systems have also been developed for the *A. gambiae* complex, and these could be applied to individual males and females. However, members of the *A. gambiae* complex exhibit only a low degree of electrophoretic allele divergence and the biochemical key could not distinguish with certainty between *A. gambiae* s.s. and *A. arabiensis.*[f]

A. beklemishevi is the first mosquito species ever named and described primarily from cytotaxonomic studies.[g]

Among the other *Anopheles* species complexes in which cross-breeding and hybrid sterility have been investigated are the *A. maculipennis* complex (comprising seven recognized Palaearctic species, namely *atroparvus*, *beklemishevi*, *labranchiae*, *maculipennis*, *melanoon*, *messeae*, and *sacharovi*, and some other Nearctic species), the *A. punctulatus* complex (*A. punctulatus*, *A. koliensis*, and *A. farauti* 1 and 2) and the *A. claviger* complex (*claviger* and *petragnanii*).

Most species of the *maculipennis* complex are characterized by different polytene chromosome banding patterns, and because of the practical applications achieved with several species of the *A. gambiae* complex (referred to above) it is hoped that in the future this technique could become applicable under field conditions to the *maculipennis* complex.

The two species of *A. farauti* in the *A. punctulatus* complex show chromosomes differing by only two fixed inversions on chromosome-2. No polymorphism has been found in this pair of species.[h]

In the neotropical subgenus *Nyssorhynchus*, many sibling species evidently exist among the medically important species. Chromosomal evidence of speciation exists in at least four nominal species: *nuneztovari*, *darlingi*, *albitarsis*, and *evansae*. All these species have clearly visible larval salivary polytene chromosomes. In South America, the Colombian and Venezuelan populations of *A. nuneztovari* (known to be vectors of malaria) differ from those of Brazil (non-vectors) by a fixed inversion in the long arm of the X-chromosome.[h] Similarly, three chromosomal types of *A. albitarsis* have recently been identified from southern and eastern Brazil and from Colombia and Venezuela (B_1, B_2, and C, respectively).

Genetic studies have proved valuable not only in the identification of sibling species, but also in the control of mosquitos, the elucidation of mechanisms of resistance, and studies of vectorial capacity and of possible changes in behaviour due to insecticide selection pressure. Highly productive colonies and early separation of sexes are essential prerequisites for sterile-male release operations. For example, an 80% increase in the produc-

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[f] MILES, S. J. A biochemical key to adult members of the *Anopheles gambiae* group of species (Diptera, Culicidae). *Journal of medical entomology*, **15**: 297-299 (1979).

[g] STEGNI, V. N. & KABANOVA, V. M. Cytoecological study of a natural population of *Anopheles* in the territory of the USSR. Report 1. Isolation of a new species of *Anopheles* in the *maculipennis* complex by the cytodiagnostic method. *Medicinskaja parazitologija i parazitarnye bolezni*, **45**: 192-198 (1976).

[h] *Species complexes in insect vectors of disease (blackflies, mosquitos, tsetse flies). Report of a WHO informal consultation, 1976.* Unpublished document WHO/VBC/77.656.

tion of *A. albimanus* pupae was obtained by controlling more accurately the water temperature and number of eggs introduced into each rearing tray.[i] A genetic sexing system has been developed for the preferential elimination of females during any of the four life stages, utilizing propoxur-susceptibility as a recessive conditional lethal.[j]

Among the factors influencing development of resistance to insecticides, genetic factors such as the presence of resistance genes, their frequency, number and combinations, dominance, and fitness are very important. Dieldrin resistance in many strains, some cases of DDT resistance, and resistance to cholinesterase inhibitors in *A. albimanus* are due to a single gene. It has been shown that the biochemical and genetic factors governing resistance may be determined by a variety of mechanisms.

Insecticide resistance

The number of anopheline species showing insecticide resistance has increased and resistance has spread geographically as well. The recent WHO Expert Committee on Insecticide Resistance recognized 51 species as resistant to at least one insecticide. Instances of double resistance to DDT and dieldrin/HCH are now very common and at least 10 species are also resistant to organophosphorus (OP) insecticides, and 4 to carbamates as well. In Asia, *A. culicifacies*, *A. stephensi*, and *A. sinensis* resistant to organochlorine, and in some areas also to OP, insecticides continue to cause serious problems for malaria control. Elsewhere, *A. albimanus* in Central America, *A. sacharovi* in Turkey and Syria, and *A. arabiensis* in Sudan cause similar problems. Multiple resistance has been of great concern in recent years in malaria vectors, particularly in areas where pesticides have been used extensively in agriculture. Whenever a vector develops resistance towards the insecticide used for its control, it is usual to investigate the cross-resistance pattern under field conditions and this has been done for *A. albimanus* in Central America and *A. sacharovi* in Turkey.

After some neglect in recent years, research on insecticide resistance is again receiving the attention it deserves from the insect toxicologists and population geneticists. Considerable work is also being done on the biochemistry of resistance. Well known mechanisms of resistance include enhanced metabolism of the toxicant by different enzymes and reduced penetration to, and sensitivity of, the target site.

PROSPECTS FOR COUNTERMEASURES

Screening of new insecticides and larvicides

The method usually followed to counteract insecticide resistance is to change to another insecticide. However, this approach is only possible if suitable alternative insecticides are available.

WHO has operated a programme for the evaluation and testing of new insecticides for about 20 years and up to mid-1977, 1737 compounds had been evaluated for their effectiveness against disease vectors and safety to mammals. Unfortunately, the number of new compounds entering the scheme has decreased progressively in recent years and this situation is of great concern. In 1978 no new compounds were received and in 1979 only six compounds were submitted for testing.

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[i] DAME, D. A. ET AL. Improved rearing techniques for larval *Anopheles albimanus*: use of dried mosquito eggs and electric heating tapes. *Mosquito news*, **38**: 68-74 (1978).

[j] KAISER, P. E. ET AL. Development of a genetic sexing system for *Anopheles albimanus*. *Journal of economic entomology*, **71**: 755-771 (1978).

Available chemicals

In addition to the older or currently employed insecticides, such as DDT, HCH, malathion, fenitrothion, fenthion, propoxur, and temephos, the following compounds are now available:

Mosquito adulticides: landrin (OMS 597), chlorphoxim (OMS 1197), pirimiphos-methyl (OMS 1424), permethrin (OMS 1821), and deltamethrin (OMS 1998). The duration of the effectiveness of these compounds ranges from 8 to 14 weeks at the recommended dosage rates, but local factors, cost, and availability may affect their suitability for use in control operations in specific areas. Bendiocarb (OMS 1394) is now undergoing field tests in Indonesia.

Mosquito larvicides: chlorpyrifos (OMS 971), jodfenphos (OMS 1211), pirimiphos-methyl (OMS 1424), methoprene (OMS 1697), and diflubenzuron (OMS 1804). The last two compounds are insect growth regulators.

Among the newer insecticides, synthetic pyrethroid compounds (permethrin and deltamethrin) show high activity, but resistance to pyrethroids might develop rapidly in field populations since DDT resistance often seems to be associated with pyrethroid resistance.

Safety of pesticides and formulations

Antimalaria programmes are the main consumers of insecticides in public health and, owing to the resistance of vectors to pesticides, a greater variety of compounds has to be used. New compounds, in addition to being effective and cheap must also be safe, particularly when the insecticides are to be used indoors for residual spraying. Over the years, WHO, in collaboration with FAO, has distributed data sheets giving information on the chemistry, use, and toxicology of about 50 pesticides, including most of those used in malaria control. The WHO Recommended Classification of Pesticides by Hazard[k] lists and classifies compounds of greater than moderate hazard.

Small amounts of certain impurities in organophosphorus compounds can influence their toxicity and, therefore, during manufacture and storage the formulations must be carefully monitored. After the 1976 episode of poisoning in Pakistan in which 5 people died, the collaborative research carried out showed that in this case the major toxic component of the malathion was isomalathion. This impurity can potentiate the toxicity of malathion in mammals by inhibiting the normal detoxication mechanisms. In view of this, the WHO Expert Committee on Chemistry and Specifications of Pesticides established new specifications for malathion water dispersible powder (wdp), imposing strict limits on isomalathion. Similarly, in 1978 the WHO Expert Committee on Safe Use of Pesticides recommended additional research on the toxicity of formulated pesticides and pure organophosphorus compounds and examination of the formulations containing carboxyl ester moieties for the presence of impurities. The Expert Committee also recommended safety measures for the personnel involved in spraying, for example, the mixers and baggers and the spraymen. Specific suggestions have also been provided on the training of operators in ways of protecting themselves from unnecessary exposure.

Expenditure on major insecticide formulations for malaria control

Malathion started to replace DDT in 1976, and by 1980, while the estimated quantity of DDT 75% wdp used in malaria control operations had fallen by nearly 30% compared with

[k] *Guidelines to the use of the WHO recommended classification of pesticides by hazard.* Unpublished WHO document, VBC/78.1 Rev. 2.

1973, the quantity of malathion 50% wdp used had increased fortyfold over the same period. Global expenditure on DDT 75% wdp for malaria control is nevertheless estimated to have increased from US$ 18 million in 1974 to US$ 35 million in 1980 owing to an average price increase from US$ 750/tonne to US$ 1960/tonne; the expenditure on malathion 50% wdp for malaria control is estimated to have increased from nearly US$ 1 million in 1974 to US$ 53 million in 1980, largely because of the increased amount used but also, in part, to a price increase from US$ 1580/tonne to US$ 2200/tonne over the 7-year period.

DDT still remains the cheapest and probably the most used insecticide for malaria control. Its use is expected to continue at a high level during the next decade, with a shift towards emulsifiable concentrates instead of wdp formulations. The demand for malathion is also expected to remain high in the next decade as it is still effective against many malaria vectors. Fenitrothion may be used instead of malathion in some countries and its use is expected to increase, though not sharply on a worldwide basis as its basic cost is higher than that of malathion. Propoxur will probably be used on a limited but increasing scale as more malaria vectors become resistant to malathion and fenitrothion. Estimates of the quantities of the five major insecticide formulations used in malaria control in 1980 are as follows:

DDT 75% wdp	—	17 941 tonnes
malathion 50% wdp	—	24 260 tonnes
temephos 500EC	—	38 500 litres
fenitrothion 40% wdp	—	500 tonnes
propoxur 50% wdp	—	523 tonnes

These quantities represent a total global expenditure of about US$ 97 million.

Search for simpler methods of application

As alternatives to the traditional application of residual insecticides, other approaches to vector control have been tried and these include ultra-low-volume (ULV) application of insecticides as aerosols or mists from the ground or the air and the use of thermal fogging. When the vector is exophilic or peridomestic in its biting and resting behaviour, sequential aerosol or fog applications can be used. This has been successfully carried out with malathion in the control of epidemic malaria.[l] Trials in Central Java showed that sequential ground applications of ULV fenitrothion at intervals of about two weeks gave satisfactory control of *A. aconitus*.[m]

Advantage can also be taken of the resting habits of the vector, insecticide being applied selectively to the lower portions of the walls, as was done in Central Java by the WHO Vector Biology and Control Research unit after it had been noted that that was where the great majority of *A. aconitus* rested. Thus a partial coverage of the walls can be employed resulting in economies on insecticide and labour, although more frequent applications may have to be considered.

Applications of larvicide may be considered under certain conditions, particularly in suburban areas, coastal villages near lagoons or water embankments, major water reservoirs, industrial complexes, or tourist resorts. The available larvicides have already been listed on page 330 and these include compounds with novel modes of action. For example, methoprene (OMS 1697) interferes with the hormonal system of insects, and diflubenzuron (OMS 1804) with the moulting processes. Some of these larvicides are costly because of the need for frequent application, the large areas involved, and the possibility of environmental contamination.

[l] KROGSTAD, D. J. ET AL. A prospective study of the effects of ultra low volume (ULV) aerial application of malathion on epidemic *Plasmodium falciparum* malaria. IV. Epidemiologic aspects. *American journal of tropical medicine and hygiene*, **24**: 199-205 (1975).

[m] PRADHAN, G. D. ET AL. *A village scale trial of ground ULV fenitrothion (OMS 43) for the control of* Anopheles aconitus *in the Semarang area of Central Java, Indonesia*. Unpublished document WHO/VBC/79.739.

Biological control

Biological control of vectors is receiving increased attention as it could become an important component of integrated vector control strategies and provide new approaches to the control of vectors resistant to conventional insecticides. There is also a possibility that certain biological control agents could be produced by communities themselves on a cottage-industry scale. Research on biological control now includes both pathogens and predators such as fish.

Pathogens

Most progress has been achieved with a spore-forming bacterium, serotype H-14 of *Bacillus thuringiensis*, and with a nematode, *Romanomermis culicivorax*, both of which are reaching the operational trial stage. Great hopes are also placed on another spore-forming bacterium, strain 1593 of *Bacillus sphaericus*, on the nematode *Romanomermis iyengari*, and on a number of fungi (*Culicinomyces*, *Coelomomyces*, *Lagenidium*, *Leptolegnia*, and *Metarhizium*).

Predators

A consequence of insecticide resistance has been increased interest in the use of larvivorous fish for the control of malaria. Although *Gambusia* has been used in North America since the turn of the century, clear-cut epidemiological evidence of the effectiveness of this approach is not generally available, except from areas of unstable or hypoendemic malaria.

The replies received to a questionnaire sent by WHO in 1974 revealed that the most commonly used species was *Gambusia*, followed by *Tilapia* and *Poecilia*. However, the efficacy of fish for mosquito control has been determined mostly on an empirical basis with remarkable results reported from some countries and disappointing results from others. A few examples of the successful use of fish for anopheline control are given below.

Poecilia reticulata and two other species have been studied for use against *A. tessellatus* and *A. subpictus* in Maldives Republic and laboratory observations in Pondicherry, India, showed that *P. reticulata* is of potential value for the control of *A. stephensi* and *A. subpictus* in wells. *P. reticulata* has also been used in Indonesia. This species thrives well under various environmental conditions, particularly in polluted waters. In Somalia, *Nothobranchius* and *Tilapia zillii* are being considered for use against malaria vectors.

When considering the use of fish for biological control, the following factors must be evaluated:

— efficiency of the species in controlling mosquito larvae
— tolerance of the fish to the environmental conditions
— possibilities of producing fish in large quantities
— tolerance to insecticides
— ecological impact of the fish introduced.

Poecilia reticulata is considered to have great potential, while some other species of carp, *Nothobranchius* and *Tilapia*, also appear to be of interest.

Environmental management

The application of environmental management measures, such as the reduction and elimination of breeding areas, by means of drainage, levelling, flushing, management of the salt concentration, intermittent irrigation, etc., has been neglected since the introduction of residual insecticides, but recently there has been a renewal of interest in these methods. Other approaches to environmental management include zoophilic deviation by management of the cattle population, individual protection from mosquito bites by the use of mosquito-nets and screens, the improvement of housing, etc.

Genetic control

Recent advances in the field of genetics have aroused some interest in the genetic control of mosquitos. A population of *A. albimanus* was reduced by 99% in an isolated lake area in El Salvador in 1972 by the release of chemosterilized males. In such cases, however, studies are always necessary to gauge the genetic heterogeneity of the target population as well as to ensure quality control of the mass-reared males so that they can successfully mate with the target females. Mechanical separation of males for release is usually done at an advanced stage of the life cycle (pupae) and may not be sufficiently effective. Genetic sexing techniques have now been developed which allow selective killing of females in the egg or larval stages, thereby permitting an enormous saving in the rearing costs. Such systems are now available for *A. albimanus,*[n] *A. gambiae,*[o] and *A. arabiensis.*[p]

Suppression or eradication of mosquito populations may be followed by the reoccupation of the ecological vacuum by the original or other species. Such a possibility may be avoided by population replacements. Refractory strains have been developed in the laboratory but, at present, none is available that is refractory to human malaria. More research is needed before any of these methods can be used in field operations.

THE INTEGRATED APPROACH

What then is the future outlook as regards the control of malaria vectors? Clearly, no single method is available that will satisfy each and every situation and it will be necessary to combine the methods best suited to the local epidemiological landscape. This will require greater involvement of local and national specialists in making thorough initial studies in order to arrive at the most appropriate combination of methods to achieve the best results and also technical cooperation among developing countries, self-help, and improved health education. In countries where the necessary national expertise is not available improved training facilities will be required.

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[n] SEAWRIGHT, J. A. ET AL. Genetic method for the preferential elimination of females of *Anopheles albimanus*. *Science*, **200**: 1303-1304 (1978).

[o] CURTIS, C. F. ET AL. A genetic sexing system in *Anopheles gambiae* species A. *Mosquito news*, **36**: 492-498 (1976).

[p] CURTIS C. F. (1978) Genetic sex separation in *Anopheles arabiensis* and the production of sterile hybrids. *Bulletin of the World Health Organization*, **56**: 453-454 (1978).