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Biotic Factors in the Control of *Aedes aegypti*

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Organisms of many kinds contribute to the natural regulation of numbers among *Aedes aegypti* populations. These include plants as well as animals; for example, certain stoneworts (Algae: Characeae) have been reported to be toxic to this mosquito's developmental stages (Caballero, 1922) and even to repel ovipositing adults (Buhôt, 1927, in reference to *Nitella phauloteles* in Queensland, Australia). Animals known to prey upon the different life-history stages of *A. aegypti* range from trombiculid mites and other scavengers which eat its eggs in laboratory storage (Jenkins, 1947) to a host of insectivores up to birds and bats encountering the adults in nature. Studies of these various predator-prey relationships are of much interest in connexion with the basic research prerequisite to a better understanding of vector-population ecology. It might also be borne in mind that fuller knowledge of scavengers causing losses among laboratory stocks of *A. aegypti* could be turned to good account in correcting such problems. However, despite the facts that Campbell's malaria-eradicating bat-roost enjoyed a brief vogue earlier in the century (Campbell, 1925) and that the same authority quotes an old belief among Mexican Indians that the appearance of large flights of dragonflies marks the waning of yellow-fever outbreaks, the practical utilization of such natural enemies against the adults of *A. aegypti* is not felt to merit serious consideration today.

The same must be said with respect to many predators on the larvae, however promising their showing in laboratory experiments conducted by various investigators demonstrating the destruction of impressive numbers of closely confined and abnormally vulnerable larval *A. aegypti* by, for example, immature stages of the tree-hole-dwelling Brazilian tipulid *Sigmatomera shannoniana* (Alexander, 1930) and the pantropical dragonfly *Pantala flavescens* (Young, 1921), which customarily develops in ground pools. Unhappily, the bulk of this mosquito's larval habitats, outside of the Ethiopian region, comprise artificial containers of one kind or another not affording appropriate conditions for the maintenance of effective populations of such predators.

Nevertheless, certain types of larvivores suited to artificial-container habitats can be and have been artificially fostered, with varying degrees of success, against *A. aegypti* and other container-utilizing mosquito vectors. Most efforts of this sort have involved the use of mosquito-eating fish, although predatory insects have been tried also.

An early field experiment of the latter kind involved the introduction of local notonectid bugs into water drums in the Bismarck Archipelago (Dempwolff, 1904); but it must be noted that these hemipterans, being winged, are likely to fly off to their preferred surface-water habitats once they have gorged themselves on the larvae in their particular container. Later introductions of *Toxorhynchites* mosquitos into several island groups, such as Fiji (Paine, 1934) are well known. Although these introductions have generally resulted in the successful establishment of the *Toxorhynchites* concerned, there is as yet little evidence of significant degrees of control of *Aedes (Stegomyia)* spp. having resulted therefrom. Perhaps the mass laboratory hatching and repeated field-release procedure now being developed by Jenner (utilizing *T. rutilus septentrionalis*) at Chapel Hill, N. C., USA, holds some future promise in this context.

Turning now to larvivorous fish, the practice of establishing small species of these in water-containers is believed to have become widespread among indigenous Central American peoples many years ago (Molloy, 1924). The potentialities of the procedure seem to have first attracted public health interest in Barbados early in this century (Morin & Martin, 1936); and were immediately exploited to good purpose during the intensive and effective sanitary campaign against *A. aegypti* on the occasion of the eradication of yellow fever from Havana. In subsequent control operations against this mosquito elsewhere in the same region, the Barbados " millions " fish, or guppy, *Lebistes reticulatus*, was deliberately introduced into many new localities.

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Some of the early attempts at such establishment failed, as in Panama (Ballow, 1908), but others were successful; the latter including those in St Thomas (Peterson & Walker, 1923), St Croix, Leeward Islands (introduction 1902 (Hayes, 1930)), and Ecuador (Myers, 1925). Elsewhere, as in Viet-Nam (Morin, 1936), difficulties sometimes arose in effecting introductions of *L. reticulatus*, apparently due to the narrow tolerances of the particular strain employed. Nevertheless, this fish is now firmly established in many parts of the tropics, notably in surface waters not utilized by *A. aegypti*, although an early introduction into the Malayan peninsula involved its successful employment against *Aedes* (*Stegomyia*) spp. and other culicines in container habitats (Strickland, 1913).

Species of *Gambusia*, formerly most commonly utilized against surface-water mosquito larvae, have been reported as of value against *A. aegypti* in areas as far apart as Tampico, Mexico (*Science*, 1921), and Batumi, USSR (Mchelidze, 1930); and the employment of *G. affinis holbrooki* in this way in Florida was being advocated with enthusiasm by Le Van of the US Public Health Service as recently as 1941. Le Van's figures show that, a year after the stocking of 2376 containers at Key West, Fla., with this fish, it was still present in 1105 of them. Only 8 (less than 1 %) of the *Gambusia*-positive containers (cisterns, wells and barrels) yielded mosquito larvae, as compared with 612 (48 %) of the remaining 1271. In Ecuador, however, *Gambusia* reportedly proved insufficiently hardy when experimented with against *A. aegypti* (Connor, 1921). The latter authority mentions that several indigenous fish were thus tested, arrangements then being made for the continued distribution of one of these (referred to by its local name of *chalaco*) to " all water containers in Guayaquil ". He states that in this manner more than 30 000 water receptacles were freed from mosquito larvae. In a later review, Connor (1922) asserts that top-feeding larvivorous fish are best for open-air fountains and similar larval habitats, bottom-feeders being best for tubs, barrels, etc., inside houses. He makes the further point that none of the fish with which he worked could be established in metal tanks, for which tight-fitting lids should be provided. (Today, larvicidal briquettes perhaps offer a more attractive solution to this particular problem.)

Various indigenous fish are claimed to have played a valuable role in yellow-fever campaigns elsewhere in Central and South America too, including British Honduras (Peach, 1923), Nicaragua (Molloy, 1924; Monroe, 1923), Guyana (Haslam, 1925, 1926), Brazil (Goeldi, 1905), and Colombia and Peru (Eigenmann, 1924).

While the utilization of natural enemies against *A. aegypti* was thus rated rather highly as a vector-control measure prior to the appearance of the synthetic organic pesticides, serious attention to the prospect of attacking this mosquito with pathogenic and parasitic organisms had to await the development of the modern discipline of invertebrate pathology. In the meantime, many records of the recovery of such organisms from *A. aegypti* accumulated in the literature. For a synopsis of this information, reference should be made to Jenkins (1964), whose list includes rickettsiae (Sellards & Siler, 1928), bacteria (e.g., von Jettmar, 1947), spirochaetes (Noc & Stévenel, 1913), *Coelomomyces* fungi (Laird, 1959), gregarine protozoa (e.g., Howard et al., 1912; Bacot, 1916), microsporidian protozoa (Kudo, 1930), ciliate protozoa of the genus *Tetrahymena* (Corliss, 1961) and mermithid nematodes, (e.g., Muspratt, 1945).

Additional records concerning organisms to which *A. aegypti* does not play host in nature include those of Liles & Dunn (1959), whose laboratory evaluation of the potentialities of *Bacillus thuringiensis* against this insect were not particularly encouraging; and Welch & Bronskill (1962), who brought about laboratory mortalities among larvae by means of the steinernematid nematode, DD136, and its associated and apparently still more lethal bacterium (*Pseudomonas* sp.).

It is obvious that a great deal more remains to be learnt about the pathogens and parasites that infect *A. aegypti* in nature; and still more about those normally found in other hosts but nevertheless able to parasitize this mosquito and cause its death. WHO's widespread survey for such organisms, now being facilitated by an International Reference Centre [1] linked with other specialized laboratories in many countries, and soon to be accelerated through the distribution to collaborating scientists of a newly developed collecting kit,[2] is leading towards the accumulation of the desired information. Already, the Organization's biological control research

[1] WHO International Reference Centre for Diagnosis of Diseases of Vectors, Department of Zoology and Entomology, Ohio State University, Columbus, Ohio, USA. This Centre is headed by Professor John D. Briggs.

[2] This equipment has since been manufactured in quantity and is available from Vector Biology and Control, World Health Organization, Geneva, Switzerland.

activities have resulted in the discovery of a new *Coelomomyces* fungal pathogen of *A. aegypti* in Rangoon, and material has been forwarded for laboratory infection experiments to M. F. Madelin of the University of Bristol, whose *Coelomomyces* life-history studies and search for an artificial culture medium are receiving support from WHO. Furthermore, laboratories in Ping-Tong, Taiwan, and in Delhi, India, are at present undertaking laboratory evaluations of a new " microbial insecticide " (based on *Bacillus sphaericus* and made available for the purpose by the Bioferm Division of the International Minerals and Chemical Corporation, Wasco, Calif., USA) against *A. aegypti* and other mosquitos. Parallel work involving *A. aegypti* is in progress in Taiwan with respect to a similar product furnished by Professor B. Schaerffenberg, of Graz University, Austria, and based upon the fungus *Isaria farinosa*.

It is anticipated that, in due course, these and related research programme activities will furnish both data on which biological and integrated control procedures for use against *A. aegypti* may eventually be based and information that will assist research workers to maintain their laboratory colonies of this vector in a thoroughly healthy state.

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