MOSQUITOFISH, A BENEFICIAL ALTERNATIVE TO PESTICIDES: PROGRESS REPORT ON ITS DEVELOPMENT AS A PRACTICAL BIOCONTROL TOOL

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Abstract. Historical and current mosquito control technologies employed in California and specifically the Sacramento-San Joaquin Valleys are described. Ample justification exists for the use of the mosquitofish, *Gambusia affinis* (Baird and Girard) as a biological control agent of mosquito larvae in permanent or semipermanent waters. Studies conducted in ricefield mosquito control indicate this fish typically provides adequate predatory activity for potential malaria and viral encephalitis vectors. Experimental earthen impoundment rearing tests and other studies are described which should result in the development of a large-scale fish culture program.

Historically, mosquito abatement interest in California was first recorded in 1904, when San Francisco Bay Area residents received aid from Professor C. W. Woodworth of the University of California at Berkeley to help control salt marsh mosquitoes (Herms, 1950). Technicians of that period followed the methods discovered and employed by the Panama Canal builders, which were to simply drain marshes or to apply cresylic acid. Kerosene and oils were soon discovered to be useful in killing mosquito larvae and were also employed; however, William T. Innes (1956) attributed the final success in the construction of the Panama Canal largely to the stocking of the mosquitofish, *Gambusia affinis* (Baird and Girard), which preyed upon the larval anopheline mosquitoes.

Malaria was widespread in California around the turn of the century when nearly 6,000 cases were diagnosed in 1909 and the Sacramento-San Joaquin Valleys were considered endemic malarial areas (Mulhern, 1973). Recognition of the mosquito as the vector of such diseases as malaria, yellow fever, and encephalitis probably stimulated much interest in mosquito control. Earlier established control techniques did not change drastically until 1945, when the era of chemical control was ushered in with the introduction of a promising new insecticide--DDT. At that time many mosquito abatement districts were formed, primarily because the mosquito-plagued residents of California communities believed they had available in DDT the final solution to virtually all their insect problems. In addition, there was some concern that servicemen returning from overseas duty would bring malaria back to this country, so even greater impetus was generated for the establishment of local abatement agencies.

By 1952, many mosquito populations had developed physiologic resistance to DDT and its overall effectiveness was soon measurably reduced. In the early fifties, organophosphate insecticides were introduced and gradually replaced DDT as the pesticide of choice. EPN, parathion and malathion were initially used with great success, but four to six years later these materials also began to lose their effectiveness as certain mosquito populations acquired resistance. Technicians now realize that the development of resistance must be anticipated with virtually every chemical agent discovered thus far. Fortunately, other means of controlling mosquito populations exist; these are the physical and biological control methodologies.

Proper physical control techniques are used to alter the microhabitat so that breeding areas for mosquitoes are eliminated or substantially reduced. Judicious land and water management techniques, as practiced by better farmers, generally prevent the development of mosquito breeding sources. However, in many situations such extensive land surface and drainage alterations are necessary that the small farmer can't afford to have the necessary work done. In these cases, the control agency tries to cooperate with the farmer to improve the situation by demonstrating proper water management to him, by suggesting different crops be planted to alter the breeding habitat, or by the integrated use of the three control techniques. If satisfactory cooperation is not achieved then legalistic methods are justified to coerce the farmer into adopting the recommended physical control plan, as current state health statutes hold the landowner fully responsible for the mosquitoes produced on his property.

Unfortunately, the culture of some crops, such as rice, naturally produce mosquitoes as a by-product; although correct land and water use by a farmer will usually not result in the production of the quantity of mosquitoes that would be generated if a farmer is negligent in his land or water management. Rice culture serves as a major source for anopheline and culicine mosquitoes --the predominant vectors for malaria and viral encephalitis, respectively. Last summer there was a resurgence of malaria in the Sacramento Valley, in which approximately 20 Plasmodium vivax infections were clinically diagnosed. The source for these cases was presumed to be at least one Asian immigrant carrying latent malaria, who suffered a relapse after entering California, thus introducing it into our mosquito populations, which in turn transmitted it to other Californians.

Presently, biocontrol techniques in this state center around the use of the mosquitofish, a native American fish of the southwestern and southeastern United States. California first received this fish in April 1922, when the California State Board of Health introduced over 500 of them into a lily pond at Sutter's Fort in Sacramento for the purpose of mosquito control (Mallars and Fowler, 1970). From that time, rapid dissemination of the species to other waters took place, as 25 mosquitofish hatcheries were established throughout the state the following year; these operations, however, were later curtailed.

Today, mosquitofish use is resurging as there has been a renewed interest in biocontrol during the last few years. The trend away from insecticide usage toward increased physical control and biocontrol techniques by the various mosquito control agencies has occurred for two reasons. First, the steadily increasing pesticide resistance demonstrated by many mosquito populations have required the agencies to apply chemicals in greater quantity and frequency to obtain previously attained levels of control. This development, in combination with recent substantial increases in the costs of pesticides and aircraft applications, have pushed expenditures beyond the operating budgets of many agencies. Allied with this problem has been the factor of population growth in formerly untreated rural areas, which have required agencies to enlarge their operational radii. Secondly, the fairly recent trend towards environmental awareness has forced many agencies to reassess and modify their modes of operation in order to comply with federal and state environmental guidelines regarding the safe use of insecticides. Bio-control begins to appear more attractive in light of these considerations; especially since current application expenditures for mosquitofish are considerably lower than the necessary repetitive insecticide application costs.

The Sutter-Yuba Mosquito Abatement District quickly recognized the environmental problems associated with the use of persistent insecticides, such as DDT and other chlorinated hydrocarbon compounds and the use of these chemicals was completely eliminated by 1963. Some vector control agencies were still applying DDT as late as 1973; but the Environmental Protection Agency has practically eliminated the use of DDT with its current restrictions. Our District's dependence on pesticides has substantially decreased in recent years as a direct result of the increased effort we have expended in solving mosquito production problems through landowner water management education, greater use of physical control techniques and the development and employment of fish as biocontrol agents.

Rice is the major cash crop produced in our two-county District and about 100,000 acres are planted to rice here every year. Blanket chemical control of the mosquitoes produced on this acreage has always been and will most likely continue to be far too expensive for serious consideration. The deleterious effects resulting from such an operation would presumably prove unacceptable. Since this rice culture requires vast areas of standing water, physical control methods can only be employed to modify those mosquito sources in the seepage and drainage margins at the perimeters of the fields.

In addition to the rice mosquito sources are many other permanent and semipermanent waters where non-biological techniques can't be justified with regard to the potential environmental degradation or to the exorbitant chemical expenditure necessary to control mosquitoes emanating from these sources.

Sutter-Yuba Mosquito Abatement District has been engaged in using mosquitofish in its overall control program since 1963. Most fish up to this date have been captured in large numbers at numerous municipal sewage oxidation/stabilization facilities where they have reproduced and grown quickly in the nutrient-rich waters of those impoundments. Unfortunately, many of the fish in the Valley impoundments have been lost in the winter months due to anaerobic conditions which have developed. At higher elevations, where more solar energy reaches the ponds during the winter months, better overwintering survival has been observed. Consequently, not nearly enough fish can be captured at all these sources to satisfy our rice stocking needs.

Stocking fish in rice is presently completed during the irrigation flooding of the fields in May and June. Recent field experiments have shown that 300 (approximately 0.6 pounds) mature mosquitofish initially stocked per acre will reproduce to the extent that they and their offspring will be able, under typical circumstances, to consume most of the mosquitoes as they pass through their larval stages (Hoy, Kauffman and O'Berg, 1972). In order to stock this District's rice approximately 60,000 pounds of mosquitofish will be needed. To date, the District has been able to stock not much more than 10,000 acres annually because of limited fish availability. An idea we tried two years ago was our plan to recapture many fish from the rice-fields during the fall draining prior to harvest and overwinter them for our use the following spring. So far, this technique has not succeeded, as the majority of the mosquitofish apparently resist the water current flow and are usually left high and dry in the drained ricefield. Other species of fish, notably carp, minnows and sunfish, are usually found mixed in the recaptured fish stocks, which indicates that any fish recaptured would have to undergo tedious examination and separation prior to placement in an overwinter holding site. As a result of that study, our District has been conducting research to learn how to best propagate and overwinter large numbers of mosquitofish in local earthen ponds of our own. Mosquitofish, a livebearer which exhibits marked sexual dimorphism, cannibalism and numerous other unique behavioral characteristics, will most likely require that cultural techniques and facilities be extensively altered from those utilized in other warmwater fish culture operations.

Many studies and experiments conducted through our District's biocontrol research program have enabled us to assess and work out solutions to some of the problems relating to the employment of biocontrol agents. This District has long been involved in innovative research programs through its own studies and cooperation with state, federal and university programs. Therefore, many diverse control methods and agents have been tested for use in the District.

Mosquitofish were screened as biocontrol agents quite some time ago and after much careful consideration, which took into account economic, ecological and physical evaluation, our District now believes that mosquitofish can provide a viable solution to the ricefield mosquito problem. There have been studies completed which report that mosquitofish can't be considered beneficial. Some competent researchers have asserted that small and possibly endangered populations of native species of fish have been replaced by the mosquitofish shortly after its introduction (Miller, 1961; Myers, 1965; and Minckley and Deacon, 1968). These occurrences were tragic and should clearly demonstrate that any new organism and its potential habitat must be thoroughly investigated before a decision is made to do any stocking. However, here in the Sacramento Valley, mosquitofish have long been employed for mosquito abatement purposes and any potential deleterious effects they may have exerted on indigenous fishes most likely took place long ago. This doesn't mean that we or any other agency should ever consider stocking new sources with any biocontrol agent without adequate knowledge as to what ecological effects may be expected. Our District has always tried to communicate and cooperate with resource agencies with regard to our biocontrol program. Within the jurisdictional confines of our District, most of the sources stocked with mosquitofish could be considered artificial in that they have been either constructed or extensively modified by man for domestic, recreational or agricultural purposes. Riparian and estuarine waters that may eventually receive our fish or their offspring usually contain many predatory species which undoubtedly forage on our fish, so that few if any, are likely to survive to colonize new habitats. I believe that when mosquitofish are properly employed, the benefits gained by their usage will far outweigh any detriments they have.

The Sutter-Yuba Mosquito Abatement District biocontrol research program centers around the propagation and employment of mosquitofish. Pond culture of this fish seems quite promising; but we must design ponds that afford maximal protection for the young from their parents. We have constructed 17 earthen impoundments that offer various degrees of shelter by way of broad littoral substrates or subsurface plateaus that become covered with emergent vegetation.

Overwintering observations have demonstrated these fish prefer deeper water in ponds during periods of inclement weather; although they usually return to surface waters on clear, calm days. Therefore, our overwintering pond designs have a variety of depths available to the fish, hopefully supplying a preferred habitat for all seasons. Many of the pond designs we have studied thus far have been rectangular in construction with varying substrate configurations. Additionally, most of the ponds have sloped substrates to facilitate draining and harvest operations. Water depths vary such that emergent vegetation can be grown in selected areas while greater depths inhibit this growth, thereby allowing open water areas.

An attempt is being made to simulate Asian fish farms where flood irrigated fields are employed to produce rice and fish. In these facilities, deep perimeter canals contain adult brood stock and the flooded crop acreage serves as habitat for the fry and production area for forage organisms. Our modified version has channels with more depth for overwinter water temperature stability, but the center has similar flooded vegetation to serve as shelter for the young and as a production zone for forage organisms.

Plankton production is presently stimulated through the use of granular inorganic fertilizers; but future cost considerations may require that we apply organic fertilizers. With respect to a supplemental feeding program, we have screened and evaluated many different commercial feeds for mosquitofish production. We are now formulating our own floating mash which contains primarily grain by-products, but has a protein content in excess of 30 percent and is only one-third to one-half as expensive to mill as the commercial feeds we tested. We hope that future refinements of our ration will result in an even better supplemental diet. To distribute this feed, which was previously done manually, we have constructed our first mechanized broadcaster, which should reduce manpower requirements significantly.

Our research facility and pilot fish farm utilizes wellwater exclusively; but no cultural effluents result from this use, as flow-through pond designs were not employed. Evaporation and subsurface seepage constitute our major water losses, but weekly pumping operations replenish the ponds.

Other fish-oriented studies are being conducted which deal with disease prevention and control, habitat analyses, water quality analyses, mark and recapture methods, fish holding tank design, seine and trap design, fish-pesticide compatibility studies and transportation techniques and equipment construction. Experiments are being conducted with the use of pure compressed oxygen release systems in our transportation tanks. We have experienced problems with other aeration equipment, such as agitators, water recirculation systems and compressed air release systems. Tests made this last summer and fall indicate that high pressure tanks and regulators connected to plastic release devices easily provide dissolved oxygen saturation of the transport water, but induced water currents that normally fatigue mosquitofish over long distance trips are practically eliminated in this system.

Another transportation technique the District has been investigating is aircraft delivery systems. Our preliminary experiments have demonstrated that mosquitofish can be successfully air-dropped into shallow ricefields with little mortality and fairly adequate accuracy. However, operational costs and logistic problems will have to be resolved if this technique is to be adopted by the District.

Other species of fish are being considered for mosquito abatement purposes. Topminnows, Fundulus sp. are now being used in the Bay Area; but continuing research is being conducted at the university and agency level on annual fishes, Cynolebias spp. and the desert pupfish, Cyprinodon macularius. At the University of California at Riverside and Davis campuses, other organisms such as fungi, hydra, nematodes and planaria are being studied for possible biocontrol applications; so one can easily detect the present impetus in biocontrol research.

This report has presented a very brief view of one aspect of the biocontrol research field, as many programs are being conducted nationwide. However, we would certainly welcome research assistance from any concerned agency, as much more must be done if man is going to substantially reduce insecticide use in the foreseeable future by utilizing more natural methods of insect control.

LITERATURE CITED

Herms, W. B. 1950. Medical Entomology. MacMillan Co., N.Y. 643 p.

Hoy, J. B., E. E. Kauffman and A. G. O'Berg. 1972. A field test of *Gambusia affinis* and chloropyrifos for mosquito control. Mosquito News 32(2):161-171.

Innes, W. T. 1956. Exotic aquarium fishes (19th Edition). Innes Publishing Co., Phila. 541 p.

Mallars, J. L. and J. R. Fowler (eds.). 1970. Mosquito eating fishes in California. Calif. Mosquito Control Asso. Press, Visalia. 27 p.

Myers, G. S. 1965. *Gambusia*, the fish destroyer. Tropical Fish Hobbyist 13(5):31-32, 53-54.

Miller, R. R. 1961. Man and the changing fish fauna of the American southwest. Papers, Mich. Acad. Sci., Arts Letters, 46:365-404.

Minckley, W. L. and J. E. Deacon. 1968. Southwestern fishes and the enigma of "Endangered Species." Science 159:1424-1432.

Mulhern, T. D. (ed.). 1973. Manual for mosquito control personnel. Calif. Mosquito Control Asso. Press, Visalia. 198 p.