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FORUM

ADVERSE ASSESSMENTS OF *GAMBUSIA AFFINIS*: AN ALTERNATE VIEW FOR MOSQUITO CONTROL PRACTITIONERS[1]

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ABSTRACT. Adverse opinions on the introduction of *Gambusia affinis* for the control of larval mosquitoes are reviewed. The sources span a period of some 59 years and come from a variety of sources. The principal opposition to the introduction of *G. affinis* comes from ichthyologists, although some mosquito researchers have expressed concerns about the environmental impact of placing the fish in habitats to which it is not native. Questions concerning the appropriateness of using the fish are presented.

Although mosquito research and control personnel have been almost unanimous in their approval of the use of *Gambusia affinis* for mosquito control, members of the ichthyological community have viewed introduction of the fish into nonnative habitats with alarm because of real and potential damage to these ecosystems. This paper presents a brief review of adverse opinions so mosquito control personnel can have another perspective to consider when planning to utilize the fish outside its native habitat.

Meisch (1985) published a 14-page chapter on *Gambusia affinis affinis* in the basic text for mosquito control workers, *Biological Control of Mosquitoes.* Writing from a mosquito control perspective, Meisch included a section on "Negative Aspects," although these negative comments were vitiated by insertion of positive statements about *Gambusia.* Bay (1985) wrote a chapter on "Other Larvivorous Fishes" in this same book. In the concluding chapter of *Biological Control of Mosquitoes,* Laird (1985) pointed out that biocontrol of mosquitoes had been almost exclusively concerned with *G. affinis* prior to commercial production of *Bacillus thuringiensis* subspecies *israelensis.* Early successes with the fish had led to widespread dispersal. Laird pointed out concern by the World Health Organization leading to a "recommendation that *G. affinis* not be introduced into new areas but that indigenous species be researched and used." He noted application of predatory agents should not result in "destruction of these already-present natural enemies of mosquitoes." Although there are many larvivorous fish, *Gambusia* has been the backbone of biocontrol for one-quarter of a century, and Laird remarked that any other biological control agents could also have adverse impacts. The effect on nontarget organisms should be reduced. Thus, Laird recommended cost/risk/benefit studies as an essential part of any control program and concluded, most realistically, that no adverse impacts would mean no mosquito control.

In 1967 Bay had reviewed positive and negative aspects of the use of *Gambusia* and later (1972) reviewed opposition to use of *Gambusia* in West Africa, citing the anti-*Gambusia* feelings of "most ichthyologists."

Another source, long familiar to mosquito control workers, is "A guide to the use of the mosquito fish, *Gambusia affinis,* for mosquito control" by Scholdt et al. (1972). Scholdt warned that "the impact of the fish on the aquatic environment cannot be underestimated as there is good evidence that the indiscriminate use of mosquito fish can be as detrimental as the misuse of pesticides."

Many of the same sentiments were echoed by

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[1] In the August 1995 issue of the *AMCA Newsletter,* President John Edman suggested that we might have a forum section in the *Journal of the AMCA* to promote scientific debate. Fortuitously, a controversial manuscript was received from Henry Rupp, entitled "Adverse assessments of *Gambusia affinis*: an alternative view for mosquito control practitioners." This manuscript appeared to be ideal for such a forum. Comments about Mr. Rupp's manuscript were solicited from a number of mosquito control or wildlife specialists who were asked to give their views on the pros or cons of Mr. Rupp's contention that the use of *Gambusia* for mosquito control may have more negative effects than positive ones. These comments now are being published with the above paper. The response of our readers to a Forum section and suggestions for future topics would be appreciated.—*R. A. Ward, Editor*

Laird (1977) who wrote, "Time has proved that mosquitofish eventually became harmful in some areas to which they were introduced half a century ago—the harm ranged from eating the eggs of economically desirable fish, to endangering rare indigenous species." Later, in 1988, Laird cited Miura's work in the rice fields of California as indicative of the lack of adverse effects on one environment, an environment Harrington (personal communication) referred to as "artificial." Laird (1988) cited Légendre's 1937 article in the *Bulletin Économique Indochine,* pointing out that the threat to indigenous fish from *Gambusia* predated Myers's 1965 article, which referred to events of the mid-1930s, but seemed unaware of Sweetman's *The Biological Control of Insects* (1936), which had preceded Légendre by a year and would have been more readily accessible to mosquito control practitioners in this country. However, Laird reminds us, "Too much should not be expected, though, of such indigenous fish in natural waters of high taxonomic diversity," and indicated, in relation to *Aplocheilus panchax,* omnivorous fish can maintain themselves well in nature without mosquito larvae, and *Gambusia* is indeed an omnivore. He also cited Russian feeling that "the general effectiveness of this fish has been disappointing."

Speaking of biocontrol programs, Laird (1988) commented on use of *Aplocheilus latipes* in Russia following tests of larval consumption rates of the fish in aquaria,

> "It is submitted that biocontrol introductions of this kind, based upon a mosquito larvivore that is very probably of far more catholic tastes than univariate laboratory experiments could reveal, are only likely to prove successful where mosquito production is unusually high in rather short-lived larval habitats harbouring a limited flora and fauna; or in more complex aquatic ecosystems where preliminary habitat manipulation is undertaken to give, for example, *Aplocheilus* unrestricted access to dense concentrations of larval Culicidae."

Service (1983) noted adverse environmental effects resulting in increased mosquito production from the use of *Gambusia,* and in 1995 he reaffirmed his doubts about the value of *Gambusia* in control for disease prevention purposes. In 1985 Mahmoud, in a study of the efficacy of *Gambusia* for malaria control in the Sudan, concluded *Gambusia,* although effective in canals and ditches, was not "an efficient mosquito control measure during the peak season of malaria transmission."

These caveats are mild compared to the opinion presented by ichthyologists Courtenay and Meffe (1989) in the conclusion to their section on *Gambusia* in *Ecology and Evolution of Livebearing Fishes,* where they state:

> "In summary, mosquito fish almost invariably present a multitude of problems when introduced beyond their native range and offer no real compensatory or biological control advantages. The species should not be used as a larvivore, with native species much preferable in that role whenever possible (e.g. Lloyd 1986). Mosquitofish are far too aggressive and predatory to be indiscriminately spread throughout the world without recognition of dangers to native biota. An international ban on their use as a control agent is biologically appropriate and warranted."

What are the reasons presented for this condemnation? Let us look at some of the evidence Courtenay and Meffe present in their review of the literature dealing with the adverse affects of the use of *Gambusia.*

The first complaint raised is that *Gambusia* is not really that effective in mosquito control and that better control has been achieved with native species (Table 1). As far back as 1949 Bates was noting, "The success of practical operations along these lines [biological control] has not been very remarkable." In 1967 Harrington (personal communication) said, "very few entomologists have sound evidence of the alleged efficacy of *Gambusia* where it has been introduced."

In Australia, Allen (1989) remarked on *Gambusia's* lack of efficacy in mosquito control, and in 1993 Dennis C. Haney of the National Biological Survey of the U.S. Department of the Interior wrote (personal communication), "I think you will find that there is little or no evidence for *Gambusia* being particularly effective in controlling mosquito larvae. In fact, almost all the evidence indicates that *Gambusia* is no better at controlling larvae than are native fish."

Recognizing there is testimony on both sides of the issue and *Gambusia* may not be so universally successful as we have been led to believe, let us turn to what ichthyologists consider a more serious issue. The failure to effect larval control is a concern of the mosquito control community, but *Gambusia's* impact on nontarget organisms affects a broader community of interests.

The concern with environmental impacts goes back more than half a century when in 1936 Harvey Sweetman warned in his pioneering *The Biological Control of Insects*:

> "Finally, it should always be held in mind that the introduction of any foreign animal is apt to cause repercussions on the native fauna in unexpected ways. *Gambusia* has been spread far and wide in anti-mosquito work, frequently in ignorance of valuable native species. *Gambusia affinis* and *G. hal-*

Table 1. Reports of unsuccessful mosquito control by *Gambusia affinis/holbrooki* (from Courtenay and Meffe [1989]; see this publication for reference citations).

Locality	Comments	Reference
Australia	It is arguable whether mosquitofish offer better mosquito control than some native fishes.	Grant (1978)
Australia	"I believe their effect on mosquitoes has been negligible."	Lake (1971)
California	Mosquitofish can increase mosquito populations by eliminating other mosquito predators.	Moyle (1976)
California	Experiment. Pupfish more effective mosquito predator in emergent vegetation; mosquitoes a problem in Owens Valley after Owens pupfish eliminated, despite mosquitofish introduction.	Danielson (1968)
California	Experiment. Native *Cyprinodon macularis* is equal in mosquito control and not as dangerous.	Walters and Legner (1980)
Iraq	Native fish also consumes mosquitoes; mosquitofish lose efficiency in presence of other organisms. Males are poor consumers.	Sharma and Al-Daham (1979)
Italy	Mosquitofish unsuccessful in eliminating *Anopheles* from running waters.	Hildebrand (1930)
Japan	Mosquitofish reduced the number of larval, but not adult mosquitoes.	Hirose et al. (1980)
Missouri	Mosquitofish are little more effective in mosquito control than the natives they replace.	Pflieger (1975)

brookii are for their size, among the most voracious and destructive of fishes, and although no reports of damage to the young of valuable food fishes in areas into which they have been introduced have appeared, it is possible that introduction into certain places will prove to have been a mistake."

Myers, writing in 1965, noted some 30 years previously "the crew of the California State Fish and Game Department's black-bass hatchery at Friant had to discontinue using *Gambusia* as a 'forage fish' with which to feed the bass. *Gambusia* was destroying a large proportion of the young bass!" He also reported removing *Gambusia* from a pond shared with goldfish and seeing the goldfish population double and redouble in 2 years.

The effectiveness of *Gambusia* as a predator as well as its omnivorous feeding patterns makes it a hazard to native species and any other aquatic organisms that can be eaten (Courtenay and Meffe 1989). *Gambusia* does not specialize in mosquito larvae and pupae (Harrington and Harrington 1961, Myers 1965, Washino and Hokama 1967, Meisch 1985). Myers (1965) reported the loss of 5 species subsequent to the introduction of *Gambusia*: *Poeciliopsis* sp. (USA), *Aplocheilus panchax* and *Phenacostethus* sp. (Thailand), *Gulaphallus* sp. (Philippines), and *Micropanchax sholleri* (Lower Nile). Courtenay and Meffe (1989) listed other species and organisms reduced or eliminated by the introduction of *Gambusia* (Table 2). Lynch (1991) reported on the impact of *Gambusia* on the plains topminnow, *Fundulus sciadicus,* in Nebraska in an experimental release program. His comments on such research are instructive: "Most experiments are done under controlled circumstances where the experimenter has some notion of what to expect .... The release of self-replicating agents into the environment is fundamentally different, because as soon as they are released, any controls are lost."

Gambusia's pugnacious and omnivorous nature is not helpful to other species' reproduction (Myers 1965). Eggs and fry, even of intensive-care fish such as the Centrarchidae, are grist for their reproductive mill (Myers 1965), and competition for resources is not the problem; it is predation (Courtenay and Meffe 1989).

Australian ichthyologists talk of *Gambusia* almost as Australian agriculturists speak of the rabbit. Brought in with good intentions, the fish has spread widely across the continent and is viewed as a threat to native species (Allen 1989, Arthington and Lloyd 1989); and, in coastal regions of southeast Asia, Bardach et al. (1972) cite *Gambusia* as well as the common guppy as pest species. Wildekamp (1993) notes the impact of the introduction of *Gambusia* on 4 species of *Aphanius* in the first of a multivolume set about killifish of the world: *A. anatoliae transgradiens* (Turkey), *A. apodus* (Algeria), *A. fasciatus*

Table 2. Examples of negative impacts of nonnative *Gambusia affinis/holbrooki* populations on local fishes (from Courtenay and Meffe [1989]; see this publication for reference citations).

Native species	Effect	Reference
20 taxa: Cyprinidae (1), Cyprinodontidae (6), Poeciliidae (9), Neostethidae (3), Gasterosteidae (1).	Reduction or elimination	Schoenherr (1981)
Cyprinus carpio	No reproduction	Sreenivasan and Natarajan (1962)
Crenichthys baileyi	Reduction	Deacon et al. (1964)
Cyprinodon calaritanus	Elimination	Missiroli (1948)
Cyprinodon bovinus, Gambusia gagei, Lepidomeda mollispinis pratensis	Partial elimination due to mosquitofish	Miller (1961)
Rhinichthys osculus	Elimination	Deacon et al. (1964)
Hypereleotris galli, Melanotaenia fluviatilis	Reduction	Arthington et al. (1983)
Eleotridae, *Ambassus castelnaui, Nannoperca australis, Craterocephalus* spp., *Melanotaenia fluvitalis, Pseudomugil signifer, Retropinna semoni*	Reduction	Lloyd (1984)

(Rhone Delta–Camargue), and *A. iberus* (Spain and Algeria).

More recently, Gratz (personal communication) wrote of a fish expert for FAO coming into his WHO office complaining about the stupidity of people releasing *Gambusia* into an area where he was trying to develop fish populations to feed indigenous populations only to find the *Gambusia* eating the eggs of the desired fish species.

It is instructive to compare the commentary on *Gambusia* in 2 standard field guides to freshwater fishes of North America. The Audubon guide (Boschung et al. 1983) notes *Gambusia* has been widely introduced for use in mosquito control. The Peterson guide (Page and Burr 1991) is much more specific: "Introductions of this species, often for mosquito control, have caused or contributed to the elimination of many populations of fishes with similar ecological requirements. Introductions into western drainages have been especially deleterious to the survival of certain rare fishes." Is it possible the Audubon Society with its known antipathy to pesticides is willing to tolerate the use of *Gambusia* as the lesser of two evils?

Are hazards posed by use of *Gambusia* real? One suspects arguments presented by ichthyologists must have substance, and the evidence presented is real. Critics of *Gambusia* ask why native species are not used to control mosquitoes. Several reasons may be posited. If a fish is in its native habitat and is an effective predator, such as saltmarsh killies, the need to institute a biocontrol program is unnecessary. However, when it comes to habitats where native fish are not as numerous or their numbers have been reduced by introduction of exotics, then cultivation and stocking of native egg-laying fish, it is assumed, take more effort. Live-bearers are supposedly easier to raise than egg-layers; fry are larger, free swimming, and feeding at birth; they grow more quickly and become predators faster. However, in this writer's experience, egg-laying minnows (*Pimphales promelas* "Rosy") produced thousands of fry in a 10-ft. garden pond over the course of a summer with minimal parental predation. *Gambusia* have proved easy to use, require minimal training for application, and, more importantly, have been thought safe. These fish have good public relations value (Duryea 1993), showing our ability to not be totally reliant on pesticides in a period of chemophobia. Further, their easy availability has allowed us the luxury of not having to seek other tools.

One question, never effectively raised, because *Gambusia* was a biological organism, was the question automatically asked about any pesticide: What are the nontarget effects? Were a label sought for use of *Gambusia* as a pesticide today, one suspects it might well prove unacceptable to the Environmental Protection Agency because of adverse environmental impacts, particularly as those effects would be revealed in the review process. Being a highly goal-oriented community, one suspects mosquito research and control people have looked at *Gambusia* with rose-colored glasses. Another question we have not asked ourselves is that if *Gambusia* is so effective a predator, how is it there are so many mosquitoes in areas that are its native habitat?

Mosquito research and control people find their origins in the disease-prevention programs of the past. Their concerns have been oriented toward human well-being, so it is not surprising they welcomed a tool such as *Gambusia.* But, if health concerns are given as a reason for introduction of *Gambusia,* it should be remembered that *Gambusia* is not an effective control against vector species such as *Aedes aegypti, Ae. albopictus, Coquillettidia perturbans,* or *Culiseta melanura.* One should also note that if disease is a factor, then control should be effected as promptly and as completely as possible. It is more responsible to use an insecticide whose environmental breakdown is a known factor rather than a biological agent whose environmental fate can only be speculated.

The recognition that there is disagreement about the use of *Gambusia* and the willingness of researchers (e.g., Laird, Meisch, and Service) to recognize and present opposing points of view make it obligatory that studies, other than specifically scientific work on *Gambusia,* take into consideration alternative opinions. Otherwise such studies risk compromising their integrity. Our thinking over the years has been conditioned by what mosquito researchers, not ichthyologists, have told us about *Gambusia* and its efficacy, particularly about the numbers of larvae consumed in aquaria or other artificial habitats. We need to expand our horizons to learn what other specialists in the aquatic world have to say about *Gambusia,* and we need to factor in that knowledge so we can avoid ecological mishaps is areas not already destablized by introduction of exotics.

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COMMENTS ON "ADVERSE ASSESSMENTS OF *GAMBUSIA AFFINIS*"

Perhaps the greatest service that Mr. Rupp has done in writing this article is to show the importance of periodically scrutinizing any method, material, or approach to vector control, even one whose efficacy has been taken for granted as long as has the use of predacious fish. Virtually every manual, brochure, or guide on mosquito control urges the use of predacious fish, usually *Gambusia affinis,* wherever possible; these reviews are usually written by vector control specialists, most of whom have little detailed information on the population dynamics of *G. affinis* or of the scattered literature qualitatively assessing the efficacy of the control effected by the species or its effect on nontarget organisms.

In addition to the references provided by Mr. Rupp on the adverse impact of mosquitofish on other fish species as well as on other mosquito predators and on the failure of the mosquito fish to provide a satisfactory level of mosquito larval control, some additional references are given below that illustrate the failure of *G. affinis* to provide satisfactory control of mosquitoes in different larval habitats. Many of these papers also observe that use of *G. affinis* puts other species of fish or invertebrate predators at risk (Bence 1982, Walton and Mulla 1991). A field trial carried out by Blaustein (1992) in California resulted in inadequate control of rice field-breeding of *Anopheles* and *Culex* mosquito larvae by *G. affinis* and *Lepomis cyanellus,* the green sunfish. The fish depressed the number of notonectid mosquito predators to a level that may have contributed to the failure of the fish to control mosquitoes. The author concluded that the conventional wisdom that fish are efficient mosquito predators in rice fields in not necessarily correct and that they probably consume efficient mosquito predators. Mulla et al. (1979), observed that *G. affinis* induces drastic alterations in the ecosystem, some of which are irreversible. Cech and Linden (1987) stocked paddies with both mosquitofish (MF) and Sacramento blackfish (BF) and then drained the paddies 12 wk later to count the remaining fish and invertebrates; the highest number of mosquito larvae were in paddies stocked with MF, a severe indictment of the degree of control provided by the species. Bellini et al. (1994) stocked 3 species of fish in rice fields in northern Italy, including *G. affinis,* and found that none of them had any significant impact on mosquito densities. As the low fecundity and internal fertilization of *G. affinis* make mass culture of the species difficult, Cech and Moyle (1983) suggested that 2 species of fish native to California, *Orthodon microlepidotus* and *Lavinia exilcauda,* which have high fecundities, could be possible alternatives for rice field mosquito control, although more research was needed. Bence (1988) observed that in some of his studies, the introduction of mosquitofish increased the abundance of mosquito larvae. For 3 years Todd and Giglioli (1983) monitored daily the number of *Gambusia* in a mangrove swamp on Grand Cayman Island and found that *Gambusia* and other small fish were unable to control *Aedes taeniorhynchus.* Other studies could be referred to that resulted in similar conclusions. With the abundance of papers from different geographical and ecological areas that report poor or no control of mosquito larvae (if not an increase in larval numbers) after the stocking of *G. affinis,* one must ask, as Mr. Rupp does, why continue to use mosquitofish at all? Overreliance on laboratory studies is part of the reason but part must be ascribed to the sheer inertia of control workers who, having used fish for a long time, take it for granted that they are effective and are quite unaware of the effect on nontarget fauna. Mr. Rupp's question as to whether the use of *G. affinis* for mosquito control should be continued must receive a negative reply.

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A variety of fish species are used for the biological control of mosquitoes, which together constitute the major successes in biological control of these Diptera. However, their application is limited to relatively permanent bodies of water where their impact on the target species varies with climate and locality. Bay et al. (1976) noted that many kinds of fish consume mosquito larvae, but only a few species have been manipulated to manage mosquito populations (note: please refer to Legner [1995] for references cited here).

The mosquitofish, *Gambusia affinis,* is the best-known biological mosquito control agent. Native to the southeastern United States, eastern Mexico, and the Caribbean area, this species was first used as an introduced agent for mosquito control when transported from North Carolina to New Jersey in 1905 (Lloyd 1987). Later it was introduced to the Hawaiian Islands to control mosquitoes, and during the next 70 years to over 50 countries. The mosquitofish is the most widely disseminated biological control agent in the world. Many of the introductions were made to control *Anopheles* species that were carrying malaria. Hackett (1937) described the usefulness of the mosquitofish in malaria control programs in Europe, noting that the fish had a definite impact on the suppression of the disease. Tabibzadel et al. (1970) reported an extensive release program in Iran and concluded that the fish was an important component in malaria eradication. Although Sasa and Kurihara (1981) and Service (1983) judged that the fish had little impact on the disease and that most evidence was circumstantial, Inci et al. (1992) observed a 50% reduction in malaria cases in southeastern Turkey after the fish became established. *Gambusia* no longer is recommended by the World Health Organization for malaria control programs, primarily because of its apparent harmful impact on indigenous species of fish (Service 1983, Lloyd 1987).

Whether this fish leads to desired levels of mosquito control in many situations is still debated. Probably an accurate assessment is revealed in a statement by Kligler (1930) that ". . . their usefulness as larvae-destroyers under local conditions where vegetation is abundant and microfauna rich enough to supply their needs without great trouble, is limited. In moderately clear canals, on the other hand, or in pools having a limited food supply, they yielded excellent results . . . ."

Contemporary uses of and successes with *Gambusia* were discussed in detail by Legner (1995). It was concluded that although the mosquitofish has been useful for control of mosquitoes in a number of situations, clearly there are environmental drawbacks to its use. This fish probably never would have been intentionally introduced into foreign areas if today's environmental concerns existed in the early 1900s. A major objection to mosquitofish has been their direct impact on native fishes through predation, or their indirect impact through competition. More than 30 species of native fish have been adversely affected by the introduction of *Gambusia.* Introductions of *Gambusia* have also reduced the numbers of other aquatic invertebrates coinhabiting the same waters. However, there are no reports of this species, through its feeding on zooplankton, causing algal blooms outside of the aquarium environment. The deployment of fish species other than *Gambusia* in mosquito control often has been restricted by inadequate supplies, or the cost of tropical and semitropical species obtainable from commercial sources has been too high for stocking large acreages.

Research into the biological control of mosquitoes has established that the natural enemy component is frequently responsible for significant population reduction and is indispensable to integrated control. Further advancements in the control of mosquitoes must continue to embrace a sound appreciation for the natural control component and nurture ways to allow its maximum expression.

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The paper by Henry Rupp is appropriate and long overdue. For decades, ichthyologists and ecologists have known, written, and spoken about the clear environmental hazards of *Gambusia affinis* and *Gambusia holbrooki* when transplanted outside their native ranges, but the mosquito control community seems to either not have heard the message or has chosen to ignore it. I support the comments and observations of Mr. Rupp in their entirety, and wish to add a few observations of my own.

First, I applaud and admire the mosquito control community for wanting to find safe alternatives to pesticide spraying. We are in agreement that such spraying is to be avoided whenever possible, and that pesticides have damaging effects, including death of nontarget species. However, the use of mosquitofish has the same effect (although not as immediate and visible), and it does not break down over time. Yes, an alternative to spraying is much desired, but I am afraid that *Gambusia* is not the answer. There may be no easy answer. But wanting something to be true does not make it so. It would be wonderful if *Gambusia* was a silver bullet with no harmful side effects, but that is not the case. I simply ask you to look at the evidence in an unbiased way.

Second, many argue that *Gambusia* are safe when used in the "contained" and artificial environments in which they often are stocked, and will not escape to the wild. This is untrue. Mosquitofish have an uncanny ability to move or be moved around—by people, by floods, perhaps by fish-eating birds who drop them in flight—but they do move. For example, I and others have found them in extremely remote areas of the desert southwestern USA that were thought to be safe and unreachable. They always seem to move, eventually.

Third, let's examine the efficacy of mosquitofish as larvivores. Do they control mosquitoes? I suspect that under certain circumstances, especially in artificial or highly disturbed habitats, they are effective. But if they are effective, then by definition they are good predators. Because we know they eat many items besides mosquito larvae, then obviously they eat a lot of other things in their new homes. By definition then, introduced mosquitofish are dangerous because they are predators on many invertebrate and vertebrate species beyond the target species.

Fourth, I have seen it argued that *Gambusia* are used primarily where native species are not present. This means either an artificial habitat, or a natural habitat so disturbed or degraded that native larvivores have disappeared. Because *Gambusia affinis* and *G. holbrooki* are so tolerant, they can survive where other fishes cannot. But this means that we are addressing the wrong problem. Rather than scattering mosquitofish across a degraded landscape, we should be using those resources and energies to restore the natural environments, including their native larvivores. We are heaping one problem on top of another, while ignoring the underlying causes. Mosquito problems are frequently an indication of environmental degradation, and should be treated as such.

In conclusion, I reiterate my earlier claim, cited by Henry Rupp, that *G. affinis* and *G. holbrooki* should not be used beyond their native ranges, and their intentional movements should in fact be banned. Yes, we need to address mosquito control in some areas, but the use of *Gambusia* is often ineffective and has repeatedly been shown to be dangerous to other biota. *Gambusia* is not the answer to the problem.

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The bottom line to Henry Rupp's article on *Gambusia affinis* is that, as in all professions, mosquito control practitioners should always know their tools. I too have extensively reviewed the literature cited by Mr. Rupp up until 1973, and am personally familiar with some of the work and observations later published. What is noteworthy is how few, speculative, and inconsequential are the statements in Mr. Rupp's tables related to the argument of adverse effects. Given the concerns of ichthyologists I find this lack of documentation over the past 22 years of renewed biological control emphasis, including the use of larvivorous fishes, to be remarkable. More significant is what the documentation says about the failures of *Gambusia.* Voluminous as it is, the literature on larvivorous fish cites relatively few well-documented successes of consequence.

Try to breed mosquito larvae in a water trough populated with *Gambusia.* It can't be done! Try to reduce biting populations of adult mosquitoes in regions of puddled swails, marshy habitats, intermittent flooding, tree holes, and a host of other larval sources by introducing *Gambusia.* It won't happen! Somewhere in between these extremes *Gambusia* meets its limits.

Gambusia has been variously described by ecologist Frank Wilson as the "most widely disseminated natural enemy in the history of biological control," and by Louis Krumholtz as "the most widely distributed of any freshwater fish." With so few documented cases of adverse effects by *Gambusia* over more than a half century one wonders at the validity of ichthyologists' concerns. Even the noted poeciliid expert, the late Carl Hubbs, wrote to Marston Bates in 1968 "We have convicted the little criminal [*Gambusia*] on circumstantial evidence to a large degree." Perhaps the most cited indictment is George Myers's paper "*Gambusia,* the fish destroyer," again referred to by Mr. Rupp. Myers relates that eliminating *Gambusia* from a goldfish pond resulted in a stable population of 11 goldfish increasing to 50 fish within 2 years. The key word should be stable. The 2 species had been coexisting and Myers simply reduced the species diversity.

Granted, there are isolated habitats into which *Gambusia* should never be placed, for example, desert pools with relict pupfish populations and in questionable habitats where introduction of *Gambusia* would contribute negligibly to overall mosquito suppression. On the other hand, Clark Hubbs, in 1972, speaking of recreational fisheries in artificial impoundments commented "The available fauna may be limited and maladapted, making supplementation by exotics beneficial and inevitable." The same logic should also apply to species used to aid human health and comfort.

Gambusia has had more than ample opportunity to star in the cavalcade of introduced species disasters, but it has never been more than a bit player. Prudent mosquito control practitioners need only cast this player in its proper role.

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I agree with much of what Mr. Rupp says about the adverse effects arising from the use of *Gambusia affinis* to control mosquitoes. In fact, I think a stronger case could have been made against the fish. Important references reviewing the successes and and failures of *G. affinis* in reducing mosquito populations and the adverse ecological effects that can be caused that were not cited by Rupp include Lacey and Lacey (1990. J. Am. Mosq. Control Assoc., 6[Suppl. 2]:1–93); Lacey and Orr (1994. Am. J. Trop. Med. Hyg. 50[Suppl.]:1–159); Legner (1995. J. Vector Ecol. 20:59–120); Lloyd (1987. pp. 156–163. *In:* T. D. St. George, B. H. Kay and J. Blok [eds.] Proc. Symp. Arbovirus Res. in Australia 4. Queensl. Inst. Med. Res., Brisbane); Reuben et al. (1990. pp. 139–158. *In:* C. F. Curtis [ed.]. Appropriate technology in vector control. CRC Press, Boca Raton, FL); Schoenherr (1981. pp. 173–203. *In:* R. J. Naiman and D. L. Stolz [eds.]. Fishes in North American deserts. Wiley Interscience, New York, NY).

Since the turn of this century, *Gambusia affinis* has been introduced into about 60 countries in efforts to control mosquitoes and as a consequence has become the world's most widely distributed fish species. There can be no disputing that the mosquitofish can cause ecological damage, and since about 1982 the World Health Organization has not supported its introduction as a biocontrol agent. With hindsight it should never have been exported outside the USA nor disseminated within the USA.

Many publications state that *G. affinis* reduces mosquito larval numbers in breeding places, but to be an effective control agent it must reduce biting densities of the *adults* and/or reduce disease prevalence. In the great majority of control programs employing larvivorous fish there has been no attempt at such critical evaluation. Nevertheless, there are reports that fish, sometimes *G. affinis,* have reduced malaria transmission in parts of Afghanistan, China, Ethiopia, Iran, Korea, Somalia, Turkey, and the Ukraine. But in most of the trials anopheline breeding has been restricted to discrete more or less permanent larval habitats such as water reservoirs in dry areas, control has been very local, and there is usually no evidence of sustained disease control. In other instances fish have been used in integrated control operations so it becomes difficult to evaluate claims that fish have played an important role in reducing biting densities or disease transmission.

In a recent symposium on the future of vector control without chemicals (Service. 1995. J. Am. Mosq. Control Assoc. 11:247–293), I was forced to conclude that chemicals will continue to play the dominant role in the foreseeable future in vector control operations. In conclusion, the benefits of fish, including *G. affinis,* in controlling mosquitoes have frequently been grossly exaggerated and often promoted by those with little ecological understanding of population dynamics or pest management. The value of fish as a practical method of mosquito control remains, at best, questionable.

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We applaud the efforts of this journal to promote scientific debate by presenting controversial and critical views on aspects of mosquito control (e.g., Rupp's article). As researchers in fish biology, aquatic ecology, and biological control of mosquitoes, we are pleased to comment on Mr. Rupp's assessment of the use of mosquitofish for biocontrol.

Rupp contends that mosquitofish have been ineffective mosquito control agents. Viewed from a global perspective, this is generally true; in many instances, mosquitofish planted for mosquito control purposes have not effectively reduced mosquito populations. However, the literature Rupp cites either contains no original data or quantitative evaluations of biocontrol efficacy (e.g., Lake 1971, Pflieger 1975, Moyle 1976, Grant 1978, Allen 1989), is difficult to assess (e.g., Danielson 1968, Hirose et al. 1980), or is misinterpreted or misrepresented (e.g., Hildebrand 1930, Mahmoud 1985). Mosquitofish performance as a biocontrol agent deserves honest and quantitative evaluation. Many of the examples of biocontrol failure can be attributed to ignorance of mosquitofish biology and of the ecology of the stocked aquatic system, and resultant stocking of mosquitofish into inappropriate habitats and/or use of inadequate or incorrect operational methods.

Rupp also contends that mosquitofish have had negative impacts on aquatic ecosystems to which they have been introduced. Ignorance of mosquitofish biology, unrealistic expectations about their performance as biocontrollers, and inadequate appreciation of the consequences of the introduction of a nonnative fish into natural aquatic habitats have been directly responsible for the very real ecological damage wrought by these fish in many parts of the world. Mosquitofish are tough, aggressive, fecund, omnivorous predators, a classic profile for a successful "invading species." This is why, under the appropriate circumstances, they can be effective biocontrol agents. The objective of mosquito control using mosquitofish should be to select and apply the fish in those specific circumstances where the possibility of control is greatest and adverse impacts on the aquatic system are minimized. The fact that mosquitofish are not exclusively mosquito predators and therefore impact nontarget organisms probably contributes to their success in providing long-term, persistent control in habitats where mosquito larvae may be present only periodically. Mosquitofish impacts on native larvivores are a serious concern that have not yet been well studied or quantified (but see Bence. 1988. J. Appl. Ecol. 25:505–521), despite frequent anecdotal and interpretive comments; this issue deserves further attention and exemplifies the potential pitfalls of mosquitofish introductions into natural aquatic systems with well-established, complex assemblages of organisms. In general, mosquitofish are most effective in artificial aquatic habitats and agro-ecosystems such as rice fields with water/fish barriers that contain relatively simple assemblages of organisms and few naturally occurring larvivores.

To address the lack of information, misconceptions, and controversies discussed by Rupp and others, and to provide biological background and operational guidelines for mosquito control personnel planning to use mosquitofish, we (in collaboration with R. H. Piedrahita, Department of Biological and Agricultural Engineering, UC Davis) have recently completed a book entitled *Mosquitofish: Biology, Culture, and Use in Mosquito Control.* The book was published by the California Mosquito and Vector Control Association and the University of California Mosquito Research Program. A continued commitment to study, publish, and discuss all aspects of the use of mosquitofish in biological control will produce greater understanding and further improvements in the use of these fish for mosquito control. Rupp suggests that the use of mosquitofish for mosquito control may have had more negative effects that positive ones. This may have been true in the past, but we propose that it does not have to be true in the future.

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Having been a broad-spectrum ecologist for half a century, I am in accord with much of what Henry Rupp has to say about the eastern mosquitofish *Gambusia affinis* (and its western relative *G. holbrooki*). However, although having long recognized that omnivorous mosquitofish and such nonselective chemical pesticides as DDT have been used unwisely against Culicidae (always excepting in times of human health crises), I reject the urging of some environmental extremists that field applications of our only useful pre-*Bti* biocontrol larvicides must be "banned."

"Ban!" is one of the more detestable buzz words of environmental activists, who are unaware of major past successes and future prospects for *Gambusia* spp. as valuable biological elements in integrated control methodologies for the reduction of populations of mosquito pests and vectors. You will notice that I continue to use the word "control," which still figures in our Association's title, rather than "management" as preferred by an increasing proportion of practical mosquito suppression specialists (including Rupp 1995).

Integrated larval control had often been practiced in due understanding of possible adverse consequences of using mosquitofish, long before Myers (1965) so dramatically fingered them as fish destroyers. In the absence of plentiful invertebrate prey in laboratory tanks and hobbyists' aquaria, *Gambusia* spp. may attack the eggs (and adults if of suitable size) or other fish sharing such confined quarters. To a lesser extent than in the latter, this undoubtedly happens in nature too. However, concern over such unintended consequences has lately been overblown, especially since Myers (1965), in those heady early days of environmental activism, used verbal overkill of Carson (1962) kind to arouse antagonism against mosquitofish, as was just being done against DDT following the publication of *Silent Spring*. The latter's chapter headings were carefully chosen for maximal shock-horror effect, for example, "Elixers of Death" and "Beyond the Dreams of the Borgias." Her book and her cohorts effectively destroyed most of the practical usefulness of DDT for mosquito control within a decade. Ironically this would have happened anyway, probably before the end of the 1970s, by rapidly developing mosquito resistance to the best and cheapest synthetic chemical pesticide that vector controllers have ever enjoyed. Sadly, the mushrooming public and consequently political opposition to DDT was a major factor in the premature cessation of WHO's Malaria Eradication Programme a quarter of a century ago. Consequently, much human sickness and death from malaria is ascribable to Carson and her followers.

A similar campaign is now being waged by some without personal experience of the field control of mosquito pests and vectors, especially in emergency situations, against *Gambusia* spp. Witness the declaration of Arthington and Lloyd (1989) that "Review of the world literature on mosquito control has not supported the view that *G. affinis* has reduced mosquito problems or the incidence of mosquito-borne diseases in Australia or elsewhere. . . apart from moderate control in parts of California . . . ." Worse, Courtenay and Meffe (1989) display unfamiliarity with their subject in urging that "Mosquitofish are far too aggressive and predatory to be indiscriminately spread throughout the world without recognition of dangers to native biota. An international ban on their use as a control agent is biologically appropriate and warranted." Had the authors' review even been confined to the very widely circulated 719 annotations (including Myers's) of Gerberich and Laird (1968), their condemnation could not possibly have been made.

There is abundant evidence in Gerberich and Laird (1968) of highly successful employment of mosquitofish against malaria vectors. Thus, soon after World War I, during which malaria had been a crucial factor in stalemating the Macedonian Campaign, Grassi and Sella evaluated the role of indigenous larvivorous fish for anopheline control in the Pontine Marshes, an extensive area southeast of Rome that had been notoriously malarious for 2 millenia (Hackett 1937). In sharp contrast to Courtenay and Meffe (1989) and Arthington and Lloyd (1989), who urged the superiority of endemic larvivorous fish to that of mosquitofish, Grassi (1923) and Sella (1926) discovered (prior to importing *G. holbrooki*) that little could be expected of native larvivores. Gerberich and Laird (1968) provided many annotations on similar successes with mosquitofish against malaria vectors in the Adriatic Islands off the Dalmation coast from 1928; in Greece from 1928 when more than a million refugees had crowded into the most malarious regions after World War I, with anopheline incidence there subsequently declining spectacularly (Hadjinicolaou 1954); and in Russia during the Great Depression. In the former USSR in 1962, the late professors W. N. Beklemischev and P. A. Petrishcheva detailed to me the extensive mass-rearing of *G. holbrooki* in swimming pools for annual aerial transportation to large numbers of anopheline larval habitats from the Ukraine to Turkestan and beyond in the late 1920s and 1930s. They contended that this major operation had been instrumental in greatly reducing malaria incidence in a period when the economic situation precluded the purchase of adequate amounts of chemical larvicides (oils and Paris green). Surely such reduction of human morbidity and mortality was of far greater importance in a crisis situation than was any associated adverse environmental impact!

Courtenay and Meffe (1989) don't seem to appreciate that by the middle of this century mosquitofish (including cold-hardy and brackish-water strains) were already established in more than 60 countries around the world (Krumholz 1948) and had perhaps become the most numerous of all freshwater fish (Hackett 1937). How unthinkably expensive their proposed international ban on these fish would prove, and what an exercise in futility!

This is not to decry rational environmentalism. Gerberich and Laird (1968) widely circulated full notice of adverse viewpoints regarding mosquitofish, including those of Myers (1965), this helping to ensure that greater attention was thenceforward given to the impact of mosquitofish on nontarget organisms—a fact evident from many of the 472 additional titles in Gerberich and Laird (1985). We must be more alert, though, to the dangers that environmentalist activism and ensuing political consequences pose to rational biocontrol aspects of mosquito suppression, including the efforts of South Pacific countries to keep out unwanted Culicidae. Thus, Senator Patrick J. Leahy (Democrat, VT) exploded two years ago (International Herald Tribune, March 29, 1994) on his "very unpleasant experience" when exposed to an aerosol disinsectization protocol on approaching Australia. However, the South Pacific lands wish to maintain their freedom from current travellers such as *Aedes albopictus* and are not impressed by the Senator's threat "to introduce legislation to protect Americans who travel to those countries." I strongly counsel members of our Association having the global environment as much at heart as I do, not to keep backing away from the real issues of control in an increasingly undisciplined world. Failing our agreement upon what constitutes rational integrated mosquito control. and then sticking with it, we could collectively find ourselves up that familiar creek, without a paddle.

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