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An Assessment of the Potential Use of *Gambusia* for Mosquito Control in Michigan

Robert C. Haas, Michael V. Thomas

Michigan Department of Natural Resources
Lake St. Clair Fisheries Research Station
33135 South River Road
Harrison Township, MI 48045

and

Gary L. Towns

Michigan Department of Natural Resources
Lake Erie Management Unit
38980 Seven Mile Road
Livonia, MI 48152-1006

Abstract.–We reviewed scientific literature and made management recommendations regarding future introduction of non-native fish species, in the genus Gambusia, for the intended purpose of controlling pest mosquitoes in Michigan. Gambusia are small, highly aggressive fish native to the southern United States that have been stocked in nearly every state. They are very predaceous and will consume small prey animals causing serious environmental damage. A number of scientific studies in the U.S. and across the world found that introduced Gambusia had negative effects on native invertebrates, fish, and amphibians. Gambusia stocked in small Michigan ponds as recently as the late 1970s failed to establish self-sustaining populations. However, a warming climate would likely increase the ability of Gambusia to overwinter in Michigan. We followed the American Fisheries Society, Policy Statement for Introduction of Aquatic Species to determine that the introduction of Gambusia into Michigan waters would have negative impacts on existing aquatic communities and fisheries, with little or no mosquito control. We recommend that Gambusia not be used for mosquito control or otherwise be introduced into the waters of Michigan. Instead, we should protect and enhance the quality of Michigan's waterways so that native fishes thrive and naturally constrain mosquito populations. Many native Michigan fish will readily consume mosquito larvae, so if stocking fish is required, we encourage stocking of native fishes, such as the fathead minnow. We also suggest alternative mosquito control methods including an educational campaign to inform people of how to reduce man-made mosquito breeding areas.

Introduction

We have reviewed the scientific literature dealing with the use of two, very similar species of non-native fishes in the genus *Gambusia* (commonly known as mosquitofish), for the intended purpose of controlling pest mosquito populations. This report summarizes our findings and presents recommendations on how we think the State of Michigan should approach this issue. *Gambusia* are small, harmless-looking, guppy-like fish. They are not native to Michigan and, although introduced here in the past, are not known to exist at this time in the wild (see Michigan Dept. Natural Resources publication "Names of Michigan Fishes", revised October, 2002).

Two species of *Gambusia* are native to the middle and southern portions of the United States and neither species was originally found in Michigan (Figure 1, top map). *Gambusia holbrooki* is native to Atlantic and Gulf drainages as far west as Alabama, and north to Maryland and Illinois. *Gambusia affinis* originally ranged from Louisiana to New Mexico, and north to Kansas and Missouri. The two species are difficult to distinguish by external morphology, and were long considered subspecies of *Gambusia affinis*. Wooten et al (1988) provided the genetic basis for the designation of two discrete species. For the remainder of this paper, the generic name, *Gambusia*, will be used to refer to both species collectively.

Introducing an exotic organism carries a substantial risk to the environment and its natural inhabitants. In many areas of the world, where *Gambusia* have been planted for mosquito control, they have caused serious environmental damage including harming or eliminating native fishes and amphibians, and disrupting natural aquatic food chains. Their traditional common name, "mosquitofish", has apparently been misleading to the non-scientific public because these fish have a popular reputation for successful control of mosquito populations. Our review of the scientific, peer-reviewed literature shows that *Gambusia* have not provided effective mosquito control in any natural setting, despite being introduced for that purpose in many parts of the world (including most of the Northern and Western U. S, Figure 1). Therefore, we have chosen to refer to them by their generic name, *Gambusia*, throughout the remainder of this document.

Mosquito control is a very large and multi-disciplinary task which goes far beyond the bounds of fishery management. In fact, mosquitoes are very successful insects that evolved over millions of years, surviving constant pressures of fish predation. Therefore, it is unreasonable to think that any fish species could provide a significant level of pest mosquito control. According to Dinsmore (2003) and the Michigan Mosquito Control Association (MMCA, personal communication) there are no pest control agencies in Michigan presently using *Gambusia*. Three successful tactics are used in many residential areas for controlling mosquitoes, all of which carry their own environmental risk. The first involves the use of EPA approved insecticides containing chemicals such as Permethrin or Resmethrin for fogging and killing the adult, flying mosquitoes. The second involves the use of EPA approved larvacides to kill mosquito larvae or eggs that may be present in standing water. The final tactic is to minimize or eliminate small, stagnant pools of water, where pest mosquitoes can lay their eggs free of any predation risk. We suggest visiting the following websites for more information on effective mosquito control methods:

- Centers for Disease Control – http://www.cdc.gov/ncidod/dvbid/westnile/index.htm;
- U.S. Environmental Protection Agency – http://www.epa.gov/pesticides/factsheets/skeeters.htm and http://www.epa.gov/pesticides/citizens/mosquitojoint.htm

The northern house mosquito, *Culex pipiens*, is the most common pest mosquito in urban, suburban, and rural settings in Michigan and the rest of the Midwestern United States. This mosquito readily feeds on birds and mammals, including dogs and humans, and is commonly considered to be the primary vector for dog heartworm, St. Louis encephalitis, and West Nile virus in this region of North America. The northern house mosquito usually lays its eggs in temporary pools of stagnant water such as those that collect in discarded tires, tin cans, old buckets, clogged rain gutters, storm drains, or catch basins. Under the right conditions, these mosquitoes can develop from egg to adult in 8-12 days. Many of these temporary water bodies are not capable of supporting any fish species. For this reason, mosquito-transmitted diseases, like West Nile virus, are just as prevalent within the native range of *Gambusia* (Figure 1 – bottom map) as they are in Midwestern areas of the U.S. like the State of Michigan where *Gambusia* do not occur.

Life history

Gambusia are members of the family Poecilidae which includes a number of popular aquarium fishes such as the guppy, *Poecilia reticulata*. The poeciliids are generally small fish that resemble Michigan's native topminnows. Most species in this family grow no larger than 10 cm long. The largest size obtained by *Gambusia* is reported to be 6.5 cm (about 3.0 inches). *Gambusia* are short-lived animals, with a maximum lifespan of just two or three years. These species exhibit sexual dimorphism with females typically being larger than males (Krumholz 1948). Males have elongated anterior anal fin rays that are used for internal fertilization. The livebearing females can produce up to five broods per year. There are generally 40 to 50 young per brood, but some extremely large broods, exceeding 100 young, have been reported. Studies have suggested that female *Gambusia*, in the northern portion of their range, tend to produce smaller broods, with larger offspring, and produce more broods annually (Haynes and Cashner 1995).

Gambusia are found in a variety of habitats including both lotic (flowing) and lentic (still) freshwaters. Although they can survive water temperatures ranging from near freezing to 41 ºC and dissolved oxygen content as low as 0.18 ppm (Krumholz 1944; Rees 1955; Ahuja 1964), over-winter survival in northern states is generally quite low. However, some northern populations have been established. *Gambusia* populations have survived in Alberta, Canada, in streams warmed by hotsprings (Crossman 1984). Warmwater effluent, such as exists at some power facilities could provide winter refugia for *Gambusia* in northern states. Shorter, warmer winters expected to occur due to climatic warming (Shuter et al. 2002) would likely increase the ability of *Gambusia* to overwinter in northern states.

History of Stocking in Michigan

The Biological Resources Division, United States Geological Survey has extensively reviewed *Gambusia* introductions and reported that throughout the last century, *Gambusia* have been stocked in nearly all of the United States (top map, Figure 1). These introductions were largely part of early efforts to combat malaria. The establishment and spread of this species in northern states has been greatly restricted because it is not generally cold tolerant. In most cases, over-wintering in colder regions requires groundwater springs or artificially warmed waters (such as warm effluent ponds).

Since 1920, there have been several introductions of *Gambusia* into colder climates. In 1923, a stock of *Gambusia* was brought from Carbondale, Illinois, 300 miles north to Winnetka where they were subjected to much more rigorous climatic conditions (Krumholz 1944). From Winnetka, Illinois, in 1933 *Gambusia* were brought further north and planted in ponds in the outlying areas of Chicago, Illinois. Krumholz (1944) reported instances where the species survived under ice coverings of 66 cm and 56 cm in ponds near Chicago through the winters of 1938-39, respectively. After surviving many winters in that area, a stock of those fish was planted in some southern Michigan ponds in 1941, and this Michigan population of *Gambusia* was reported (Krumholz 1944) to have survived under solid coverings of ice in nine ponds near Ann Arbor, Michigan. Hubbs and Lagler (1983) noted that *Gambusia* had been introduced into Michigan as a mosquito control measure and some local populations had been established.

Overwinter survival of *Gambusia affinis* in central Michigan was studied during the winter of 1975-76 by Towns (1977). *Gambusia* survived in four of six ponds during the winter of 1975-76, but the survivors seemed to be weakened and very vulnerable to both bird and fish predation. Their presence during spring, in all four ponds, indicated reproduction had been successful during the summer of 1976.

At least two organized, large-scale attempts were made in recent times to use *Gambusia* for mosquito control in Michigan. The Lansing Vector Control Service used *Gambusia affinis* for several years from 1964 through the late 1970s. These fish were over-wintered indoors and then stocked in vernal wetlands and small ponds in and around the cities of Lansing and East Lansing (Goodsell 1975). Dinsmore (2003) stated that *Gambusia* were used in Bay, Midland, and Saginaw counties in the late 1970s. However, the fish did not over-winter and large numbers had to be kept in indoor rearing tanks through the winter months in order to have adequate quantities of fish to stock in the spring.

In light of the West Nile virus outbreak, Michigan residents have expressed interest in the application of *Gambusia* as a mosquito control agent. Much of this interest is likely a result of the ongoing use of these fish for such purposes in other states. For example, employees of some state and local health departments, mostly within the native range of *Gambusia*, apparently viewed their use to control mosquito larvae as an attractive alternative to pesticides, or as one element of an integrated approach to pest control. An internet search revealed that *Gambusia* have been advocated as a mosquito control agent in only a few states including: Maryland, New Jersey, New York (New York City wastewater treatment plants), California, Virginia, Illinois, and Colorado – and *Gambusia* is native to most of them. However, most internet references relating to pest control in these states do not refer to the negative effects of *Gambusia* on other species, and do not claim measurable pest mosquito control has occurred where these fish have been stocked. Even so, the rising interest in the introduction of *Gambusia* as a mosquito control agent in Michigan has prompted our consideration of their potential use in Michigan.

The MDNR supports the evaluation of all potential fish introductions as outlined in the American Fisheries Society, Policy Statement for Introduction of Aquatic Species (Policy Statement #15) described initially by Kohler and Courtney (1986). Our evaluation follows:

Steps 1-3 in the American Fisheries Society Protocol for Introduction of Aquatic Species

Rationale

Mosquito-borne disease remains a public health concern (humans and other mammals) and a biological control is desirable. Some elements of the public are interested in introducing the non-indigenous fish species, *Gambusia*, into Michigan for the purpose of mosquito control.

Search

Mosquito control interest groups have identified *Gambusia* as the best candidate fish species for control of disease bearing mosquitoes. Some characteristics that make them an apparently desirable candidate include: topwater feeding behavior, tolerance for low oxygen conditions, voracious appetite, ease of culture, and ability to thrive under a variety of environmental conditions.

Preliminary impact assessment

The introduction of *Gambusia* into Michigan waters would likely result in mainly negative impacts to existing aquatic communities and associated fisheries, with little or no widespread control of mosquito adults. Our evaluation was based on the review of scientific studies on the effects of *Gambusia* introductions around the world. The following sections, Effects of *Gambusia* on Mosquito Populations and Effects of *Gambusia* on Native Biota, provide a detailed synopsis of those research results. A third section provides our suggestions for native Michigan fish species which could be used as an alternative to *Gambusia* for mosquito larvae predation.

Effects of *Gambusia* on Mosquito Populations

Gambusia have been purposely introduced throughout the world in the mistaken belief that they control mosquitoes better than native, larvae-eating fishes (Courtenay and Meffe 1989). According to Lloyd (1984), *Gambusia* are far too aggressive and predatory to be indiscriminately spread outside their native range without recognition of dangers to native biota. The northern and western United States, Asia, Australia, New Zealand, Africa, Hawaii, and South America are among the locales where these fish have been introduced with the primary intention of controlling mosquito disease transmission (mostly for malaria). The role of *Gambusia* in the control of malaria has been judged not successful (Mahmoud 1993; Service 1989). Despite numerous investigations of *Gambusia*'s effectiveness in controlling mosquitoes and mosquito-born diseases, no scientifically documented mosquito control success stories have been written.

Gambusia were first stocked in Australia in 1929 for mosquito control and their stocking continued widely across the country into the 1950s. Arthington and Lloyd (1989) reported that there was no firm evidence that they were especially effective. Their studies showed that introduced *Gambusia* were, in fact, poor mosquito predators. They found that, at most, the *Gambusia* diet consisted of only 10% mosquitoes and that four native fish species of similar size consumed more mosquitoes. They reviewed the world literature on mosquito control and could not find scientific evidence that *Gambusia* reduced either mosquito problems or the incidence of mosquito-born disease. Several other studies also found that the effect of *Gambusia* on mosquitoes in Australia had been negligible (Lake 1971; Grant 1978). In addition, several authors observed that *Gambusia* may have encouraged mosquito populations by preying on their invertebrate predators and competitors (Stephanides 1964; Hoy et al. 1972; Hurlbert et al. 1972; Hurlbert and Mulla 1981). Where good mosquito larvae control has been reported, the evidence was largely anecdotal or derived from poorly designed experiments (Courtenay and Meffe 1989; Rupp 1996). Studies in Australia showed that *Gambusia* were an inefficient mosquito predator, with mosquitoes only making up a small part of the diet (Lloyd 1984, 1986). Most Australian biologists apparently believed that endemic fish provided a preferable alternative to introduction of the exotic *Gambusia*. *Gambusia* also failed to perform in New Zealand as the mosquito control advocates proposed. According to McDowall (1987), *Gambusia* were introduced with the intention of using them to control mosquitoes, but their effectiveness and superiority over native fishes was never demonstrated.

There was considerable disagreement over the effectiveness of *Gambusia* in controlling mosquito numbers in the U.S. during the 1960s and 1970s. Some laboratory studies demonstrated that individual fish could consume up to 100 mosquito larvae per day. However, documentation of mosquito control in natural waters in the U.S. has been quite inconsistent. Towns (1977) found 87% percent fewer mosquito larvae and pupae in Central Michigan vernal, fishless ponds stocked with *Gambusia affinis* compared to similar ponds not stocked with fish. However, this study did not look at ancillary impacts to native fauna, nor at whether stocked native fishes would have had a similar impact on mosquito numbers. Also, small scale efforts using *Gambusia* to control mosquito larvae and pupae may have almost no effect on populations of adult mosquitoes. Bence (1988) concluded that *Gambusia* might control mosquito production in California rice fields but that the opposite, or increased mosquito numbers, could also occur if *Gambusia* consumed predaceous invertebrates that would have eaten mosquito larvae. Another rice field study (Blaustein and Karban 1990) revealed that comparing adult mosquito abundance in the presence and absence of *Gambusia* may overestimate control: first, in the presence of *Gambusia*, mosquito development is accelerated, thus turnover of mosquitoes is greater; second, even if mosquito larvae survival is reduced in the presence of *Gambusia*, the individual mosquitoes that do survive grow larger and have a higher reproductive rate. There is even some scientific evidence that a heavy diet of mosquito larvae would not support a healthy population of *Gambusia*. Reddy and Pandian (1972) found heavy mortalities of *Gambusia affinis* reared on a diet restricted to mosquito larvae, and the few survivors showed poor growth and delayed maturation.

Effects of *Gambusia* on Native Biota

Interactions at higher levels of the food chain have a cascading influence down through lower levels due to indirect effects of predators on plants via herbivores. The basic premise of trophic cascades is that size-selective predation determines community composition at many different trophic levels including piscivore, planktivore, herbivore, phytoplankton, and nutrient levels (Kitchell and Carpenter 1993). Many important native fishes, such as the bluegill (*Lepomis macrochirus*), selectively feed on large zooplankton (Mittelbach 1983). Severe predation pressure on large zooplankton can result in increased phytoplankton biomass and unpredictable, but significant changes in zooplankton biomass (Mittelbach et al. 1995). Additional predation pressure from stocking of non-native planktivores could lower zooplankton prey availability for native fishes (like bluegill), amphibians, and other aquatic predators.

When stocked in waters outside their native range, *Gambusia* have often caused serious negative ecological impacts. *Gambusia* are opportunistic predators with a highly variable diet that includes algae, zooplankton, aquatic insects, as well as eggs and young of fish and amphibians. Garcia-Berthou (1999) documented a diet shift from diatoms to cladocerans to adult insects as *Gambusia* matured. They are voracious, highly aggressive fish that compete very successfully with native fishes for available food and space. In experimental ponds, *Gambusia* essentially depleted all large zooplankton, while rotifers and phytoplankton densities increased (Hurlbert and Mulla 1981; Bence 1988). Because *Gambusia* consumed a high percentage of the phytoplankton grazers, they indirectly caused adverse ecological changes including increased phytoplankton abundance, higher water temperatures, more dissolved organic phosphorous, and decreased water clarity (Hurlbert et al. 1972).

Some attempts to control mosquitoes with Gambusia have resulted in impacts to other aquatic insects. *Gambusia* reduced the abundance of the mosquito, *Culex tarsalis*, in a California rice field, but also reduced the abundances of other invertebrate taxa including predatory aquatic insects (Bence 1988; Hurlbert and Mulla 1981). *Gambusia* have also been implicated in declines in native damselfly populations in Hawaii due to direct predation on nymphs (Englund 1999).

A number of scientific studies in the U.S. and across the world have found that stocked *Gambusia* can have very negative effects on native fish and amphibian populations. Introduced *Gambusia* have been particularly destructive in the American West where they have contributed to the elimination or decline of populations of federally endangered and threatened species (Courtenay and Meffe 1989). While not very effective in controlling mosquitoes, *Gambusia* have been extraordinarily successful in colonizing most of the warmer areas where they have been introduced (Courtenay and Meffe 1989). *Gambusia* possess a unique array of biological characteristics that allow them to out-compete many native fishes. These characteristics include specialized reproduction, very high aggression level, and broad physiological tolerance (Courtenay and Meffe 1989). *Gambusia* are known to prey on eggs, larvae, and juveniles of various fishes, including those of largemouth bass. They are also known to prey on adults of smaller fish species. *Gambusia* are difficult to eliminate once established (Meffe 1983; Marsh and Minckley 1990), and the best way to reduce their effects is to control their further spread. One of the main avenues of spread is continued, intentional release by mosquito-control agencies.

In Nebraska, *Gambusia* appear to be displacing the plains topminnow *Fundulus sciadicus*. One of the major reasons for the decline of the Gila topminnow is predation by nonindigenous *Gambusia*, which prey on juvenile topminnows, harass adults (Meffe 1985), and swarm through whatever stabilized habitat they colonize. Meffe et al, (1983) found that *Gambusia* are very aggressive, even toward larger fish. They often attack, shred fins, and sometimes kill other species.

Introduced *Gambusia* have harmed aquatic ecosystems and faunas almost everywhere because of their highly predaceous habits. They have been especially devastating in the American Southwest, where they interact with a wide range of endangered and threatened native fishes, most notably the Gila topminnow. Schoenherr (1981) found that introduced *Gambusia* in Arizona replaced native Gila topminnow *Poeciliopsis occidentalis* by preying on their young and acting aggressively during most interactions. The topminnow was formerly the most abundant fish in the southern half of Arizona but is now endangered, with only 13 remaining natural populations (Meffe et al. 1983). Schoenherr (1981) also reviewed the scientific literature and found that introduced *Gambusia affinis* was often piscivorous and was implicated in the reduction of native populations of at least 22 different fish species. In another study, Meffe (1983) found that introduced *Gambusia* rapidly replaced the native Gila topminnow in Arizona springbrooks by consuming them. Temporary elimination of *Gambusia* was obtained with Antimycin A, allowing recovery of the topminnows, but *Gambusia* soon returned and again eliminated the native fishes.

Gambusia have also reduced or eliminated endangered pupfishes *Cyprinodon* and springfishes *Crenichthys* in Arizona, California, and Nevada (Minckley et al, 1991). *Gambusia* are difficult to eliminate once established (Meffe 1983; Marsh and Minckley 1990), and the best way to reduce their effects is to control their further spread. Introduced *Gambusia* are also considered to be responsible for the elimination of the least chub *Iotichthys phlegethontis* in several areas of Utah (Whitmore 1997).

In Australia, Barrier and Hicks (1994) found that introduced *Gambusia* were very aggressive toward native mudfish (*Neochanna diversus*) and preyed heavily upon their young. Ivantsoff and Aarn (1999) found that *Gambusia* preyed on larvae of several different fish species. Milton and Arthington (1982) found that *Gambusia* had become well established in 90% of urban creeks in Brisbane, Australia and that *Gambusia* out-competed two other exotic swordtail species *Xiphoporus* that were also introduced into the area. Howe et al, (1997) found that, in captivity, introduced *Gambusia holbrooki* had a very deleterious effect on breeding success of the native surface feeding fish *Pseudomugil signifier*.

Gambusia predation on amphibians is also well documented. Hurlbert and Mulla (1981) noted the absence of tadpoles from ponds containing *Gambusia*. Pacific treefrog tadpoles were found in 65% of *Gambusia* stomachs from California streams (Goodsell and Kats 1999). In fact, Goodsell and Kats (1999) found that *Gambusia* preyed heavily on treefrog tadpoles even when high densities of mosquito larvae were available as alternative prey. Red-legged frog tadpoles suffered more injuries and weighed 34% less at metamorphosis in ponds with *Gambusia* (Lawler et al, 1999). *Gambusia* were implicated in the extirpation of the California newt salamander from several streams in that state through predation on the egg and larval stages of the newt (Gambradt and Kats 1995). Several of Michigan's native amphibians are listed as threatened or endangered and most of the others are undergoing significant population declines. In some cases, Michigan's native salamanders require fishless vernal ponds for successful breeding (Harding and Holman 1992). Release of another exotic amphibian predator and competitor like *Gambusia* into the wild, intentional or not, would not constitute prudent resource management.

Native Michigan Fish as Mosquito Larvae Predators

Many native Michigan fish will readily consume mosquito larvae when the opportunity arises. Several species of native fishes can be cheaply reared and planted in any suitable Michigan water without the added environmental risks associated with exotic fish. These include three species of topminnow (western banded killifish, *Fundulus diaphanous menona*; starhead topminnow, *Fundulus dispar*; blackstripe topminnow, *Fundulus notatus*) and some minnow species in the family Cyprinidae. In particular, the fathead minnow, *Pimephales promelas*, is easily cultured, tolerant of environmental extremes, and will readily prey on mosquito larvae.

Suggested Course of Action

1. After reviewing the scientific literature, we definitely endorse the opinion presented by Courtenay and Meffe (1989) in the conclusion to their section on *Gambusia* in *Ecology and Evolution of Livebearing Fishes*: "In summary, mosquitofish almost invariably present a multitude of problems

when introduced beyond their native range and offer no real compensatory or biological control advantages".

Therefore, we recommend that *Gambusia* not be used for mosquito control or otherwise be introduced into the waters of Michigan.

2. Virtually every species of fish native to Michigan will eagerly consume mosquito larvae during some, or all stages of its life. Our recommendation is to protect and enhance the quality of Michigan's waterways so that native fishes thrive and naturally constrain mosquito populations.

3. In private ponds or other types of temporary private waters, if fish are going to be introduced for control of mosquito larvae, we encourage stocking of cheap, easily obtained native fishes, such as the fathead minnow.

4. The majority of pest mosquitoes probably grow up as larvae in small, stagnant pools of water incapable of supporting fish, including all native fishes and *Gambusia*. We suggest alternative control methods including an educational campaign to inform people of how to reduce man-made mosquito breeding areas like old tires, tin cans, clogged gutters, etc.

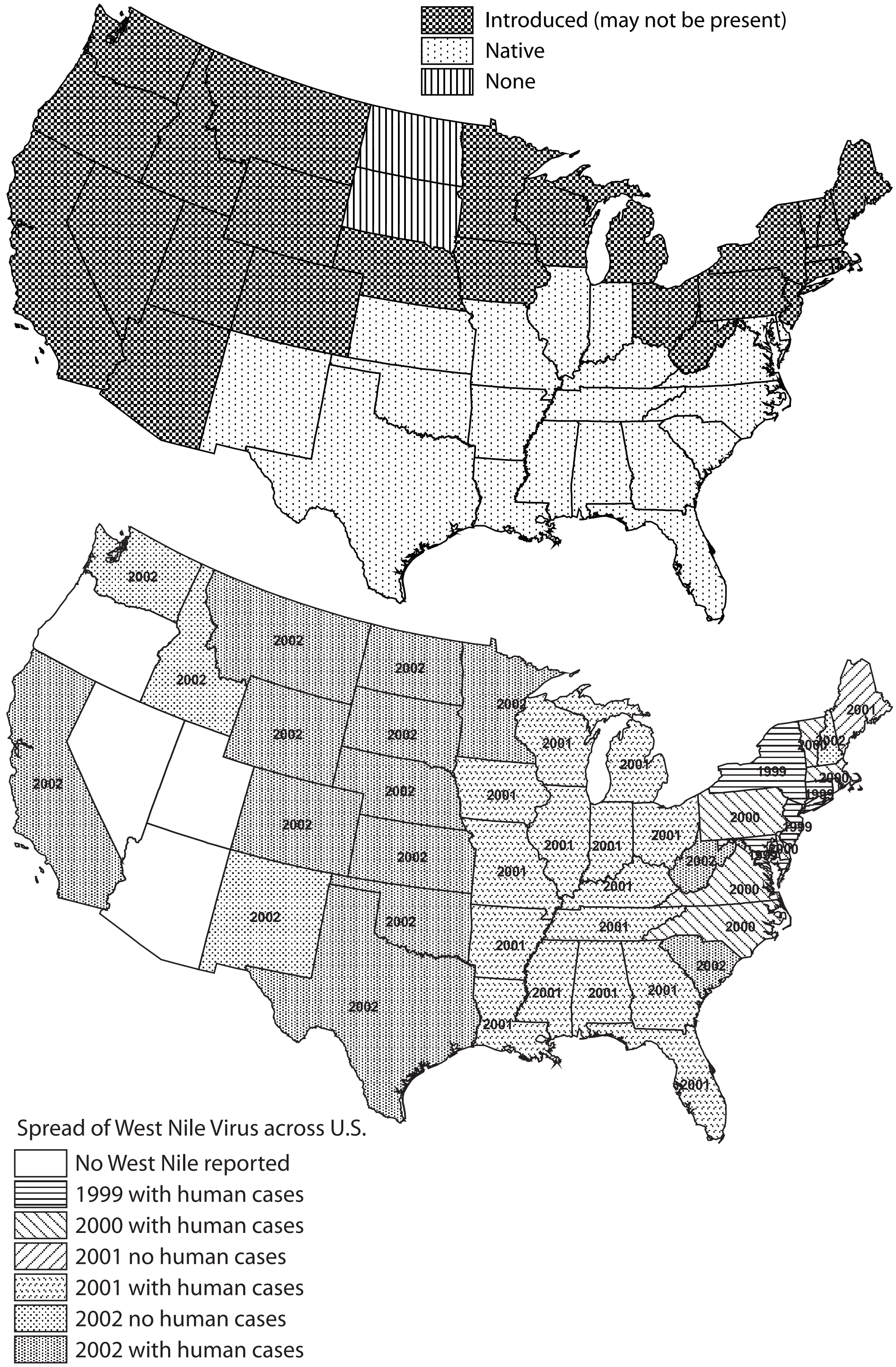

Figure 1.–Maps of the continental United States showing the native and stocked range of *Gambusia* (top map) and the geographical spread of the mosquito-born disease, West Nile virus from East to West during the period from 1999 through 2002 (bottom map). Data for top map taken from the United States Geological Service website at http://canal.er.usgs.gov/fishes/maps.html. Data for bottom map taken from the Center for Disease Control's National Center for Infectious Diseases website at http://www.cdc.gov/ncidod/dvbid/westnile/index.htm.

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Paul W. Seelbach, Editor
Alan D. Sutton, Graphics
Ellen S. Grove, Word Processor and Desktop Publisher
Approved by Paul W. Seelbach