Eastern Mosquitofish (*Gambusia holbrooki*)

Ecological Risk Screening Summary

U.S. Fish & Wildlife Service, December 2016
Revised, October 2017, November 2017
Web version, 8/16/2018

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1 Native Range and Status in the United States

Native Range

From Nico and Fuller (2016):

"*Gambusia holbrooki* is native to Atlantic and Gulf Slope drainages as far west as southern Alabama […] (Rauchenberger 1989; Page and Burr 1991)."

Status in the United States

According to Nico and Fuller (2001), mosquitofish have been stocked in Alabama, Alaska, Arizona, California, Colorado, Connecticut, Florida, Hawaii, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Jersey, New Mexico, New York, North Carolina, Ohio, Oregon, Pennsylvania, Tennessee, Texas, Utah, Virginia, Washington, West Virginia, Wisconsin, Wyoming, and possibly other states.

Means of Introductions in the United States

From Nico and Fuller (2001):

"Because of their reputation as mosquito-control agents, both *G. holbrooki* and *G. affinis* have been stocked routinely and indiscriminately in temperate and tropical areas around the world. In the United States the first known introductions of mosquitofish took place in the early 1900s (Krumholz 1948). […] Also, in 1905 *Gambusia*, reportedly from North Carolina, were released into New Jersey waters for the purpose of controlling mosquitoes (Seal 1910; Krumholz 1948). Mosquitofish were commonly and widely introduced during the following decades by such organizations as the former U.S. Public Health Service, in large part because they were thought of as an effective and inexpensive means of combating malaria (Krumholz 1948). In more recent years, employees of many state and local health departments apparently view the use of mosquitofish to control mosquito larvae as an attractive alternative to the use of insecticides. In some areas range extensions have occurred through natural dispersal far from sites where originally introduced (e.g., Pflieger 1997)."

"*Gambusia holbrooki* was introduced into New Jersey (Fowler 1952) and into Tennessee near Knoxville and maybe to other locations as well (Starnes, personal communication). Both species have been introduced into Alabama (Boschung 1992). Shapovalov et al. (1981) indicated that both species were introduced into California, but Swift et al. (1993) argued that *G. holbrooki* never has been taken in the state and probably never was stocked. There was even mention that a hybrid between the two species was released into California waters (Dill and Cordone 1997). In their recent tome on fishes introduced into California, Dill and Cordone (1997) related their strong suspicions that pure *Gambusia holbrooki* had been introduced into that state. They based their conclusion, in part, on the importance and size of the mosquito control program in California, and the central role mosquitofish played in those attempts. However, Dill and Cordone did admit that there was no real proof that *G. holbrooki* became established in the state.

In some cases *Gambusia* stocks native to a particular region of a state were moved within the same state, in Virginia for example (Jenkins and Burkhead 1994). In contrast, Krumholz (1948) reported that mosquitofish from southern Illinois, where the species is native, were introduced into northern Illinois, an area outside its native range. Hubbs and Lagler (1958) reported that intergrades between *G. affinis* and *G. holbrooki* have been introduced into southern Michigan, but the stock did not become established. […]"

From Nico and Fuller (2016):

"Established in most states where stocked outside its native range. Its establishment and spread in northern states is greatly restricted because the species are not, in general, cold tolerant. In most cases, overwintering in colder regions requires surfacing groundwater springs (e.g., Woodling 1985; but see Lynch 1988b). Established in Nebraska, although the populations suffer heavy (up to 99%) winter mortality (Haynes 1983). […]"

Remarks

From Nico and Fuller (2001):

"[…] The identity of some mosquitofish populations introduced into selected areas is correctly known. In most cases this is because the source of the stock was reported. […]"

From Nico and Fuller (2016):

"These two species [*Gambusia holbrooki* and *G. affinis*] were long considered subspecies of *G. affinis*, and were only recently recognized as separate species (Wooten et al. 1988; Rauchenberger 1989; Robins et al. 1991). Complicating matters of identification, most introductions occurred before the recent taxonomic change; furthermore, the origins of introduced stocks were usually unknown or unreported. In addition, both forms were widely available and thought to have been dispersed widely by humans. As a consequence, it often is not possible to determine if many of the earlier records represent introductions of *G. affinis* or of *G. holbrooki*."

From CABI (2016):

"This datasheet focuses upon *Gambusia holbrooki*, although much of the biology is confused between the previous subspecies and now congeners, *G. holbrooki* and *G. affinis*. Therefore, unless specified, reference to Eastern *Gambusia* or *Gambusia* refers to both species. Data for both species is also presented because both species were both regarded as *Gambusia affinis* prior to 1988 and even after this date workers often referred *Gambusia affinis* as a generic name for both species."

From NatureServe (2016):

"Formerly regarded as a subspecies of *GAMBUSIA AFFINIS*; elevated to full species status by Wooten et al. (1988); this change was adopted in the 1991 AFS checklist (Robins et al. 1991). Page and Burr (1991) retained *HOLBROOKI* as a subspecies of *AFFINIS*, noting intergradation in the Mobile Bay basin. Apparently hybridizes/intergrades with *G. AFFINIS* in some sites in the Chattahoochee and Savannah river [sic] drainages (Lydeard and Wooten 1991). In three drainages in Georgia, South Carolina, and North Carolina, most of genetic divergence occurred among local populations and not among populations from different geographic regions or environments; the 2 forms proposed by Wooten et al. (1988) were not detected in genetic analysis by Hernandez-Matich and Smith (1990). Subgenus *ARTHROPHALLUS*, *AFFINIS*

species group (Rauchenberger 1989). See Rauchenberger (1989) for a study of the interrelationships of the subgenera and species groups within the genus *GAMBUSIA*."

2 Biology and Ecology

Taxonomic Hierarchy and Taxonomic Standing

According to Eschmeyer et al. (2017), *Gambusia holbrooki* Girard 1859 is the valid name for this species; it is also the original name. In the past it was considered a synonym or valid subspecies of *G. affinis*.

From Froese and Pauly (2016a):

"Kingdom Animalia
Phylum Chordata
Class Actinopterygii
Order Cyprinodontiformes
Family Poeciliidae
Genus *Gambusia*"

Size, Weight, and Age Range

From Froese and Pauly (2016b):

"Max length: 3.5 cm TL male/unsexed; [Riehl and Baensch 1991]; 8.0 cm TL (female)"

From GISD (2016):

"Females are also larger than males with maximum standard lenghts [sic] of 60mm and 35mm respectively."

"Females can live for up to 15 months."

Environment

From Froese and Pauly (2016b):

"Freshwater; brackish; benthopelagic; pH range: 6.0 - 8.8; dH range: ? - 40; potamodromous [Riede 2004]. […]; 15°C - 35°C [assumed to be recommended aquarium temperature] [Riehl and Baensch 1996]; […]"

From GISD (2016):

"*Gambusia holbrooki* prefer warm, slow flowing or still waters, and […] in water depths of 10cm or less (Merrick and Schmida 1984; McDowall 1996; Arthington et al. 1999). Although *gambusia* [sic] can tolerate a broad range of environmental conditions, they tend to avoid rapid discharge, […] (Meffe 1984; Arthington et al. 1990; Galat and Robertson, 1992)."

Climate/Range

From Froese and Pauly (2016b):

"Subtropical; […]; 40°N - 31°N, 89°W - 74°W"

Distribution Outside the United States

Native

Gambusia holbrooki has a native range fully contained in the United States (Nico and Fuller 2016). See Section 1 for description of native range.

Introduced

From GISD (2016):

"Introduced to numerous countries around the globe on all continents except Antarctica."

From Froese and Pauly (2016b):

"Established throughout southern Europe; introduced worldwide in tropical and subtropical countries [Kottelat and Freyhof 2007]"

FAO (2016) reports introductions of *Gambusia holbrooki* to Portugal, Spain, Australia, Hungary, Uzbekistan (Syr Darya basin), Iran, Lebanon, Saudi Arabia, United Arab Emirates, Yemen, France, Madagascar, Italy, Ethiopia, Madagascar, Turkmenistan, Iraq, Syria, Turkey, India, Armenia, Bulgaria, Mauritius, and Reunion.

From CABI (2016):

"The species (both *G. affinis* and *G. holbrooki*) have been introduced across […] much of southern Canada, parts of South America, Australia, New Zealand, Papua New Guinea, Indonesia, Many Pacific Islands, SE Asia, China, Japan, India, throughout Europe and the Middle East, South Africa, and parts of Northern Africa (Lloyd, 1987)."

"Only *G. holbrooki* has been identified in the current field records and museum collections that exist in Australia (Lloyd and Tomasov, 1985). Stocks of Eastern *Gambusia* have been found in many isolated water bodies in central Australia, suggesting that natural events such as floods aid their dispersal (Lloyd, 1987; Chapman and Warburton, 2006)."

NOBANIS (2016) lists *Gambusia holbrooki* as introduced to the European part of Russia in 1925. This introduction did not establish a population and it is not considered invasive. The database also lists *G. holbrooki* as introduced to Germany in 1978. It is not known if an established population resulted or if there were any impacts.

Gambusia holbrooki is regulated under the Invasive Alien Species Act of Japan (National Institute for Environmental Studies, Japan no date).

Means of Introduction Outside the United States

From GISD (2016):

"Introduction pathways to new locations
Natural dispersal: Flooding events contribute to dispersal
Pet/aquarium trade: Obtained as feeder fish from aquariums

Local dispersal methods
Intentional release: Human disposal of aquarium fish into creeks, regurgitated by wading birds
On animals: Possibility of individuals caught in plumage of wading birds
On animals (local): Possibility of individuals caught in plumage of wading birds
Other (local): Human disposal of aquarium fish into creeks"

From CABI (2016):

"Eastern *Gambusia* has become the most widely distributed freshwater teleost in the world (Krumholz, 1948) mainly through deliberate human introductions (e.g. Lintermans, 2004). Throughout the world, it has been widely distributed to aid mosquito control in rice paddies and natural waters (Krumholz, 1948; Lloyd et al., 1986; Arthington and Lloyd, 1989). Worldwide introduction of Eastern *Gambusia* has occurred since the first introduction into Hawaii in 1905 (Krumholz, 1948)."

"However, it is human activity that has most aided the dispersal of Eastern *Gambusia*, largely through projects aimed at mosquito control on a local, national and global scale (Arthington et al., 1983)."

Short Description

From Froese and Pauly (2016b):

"Dorsal spines (total): 1; Dorsal soft rays (total): 7; Anal spines: 1; Anal soft rays: 9"

From GISD (2016):

"Greenish olive to brown on the back, the sides are grey with a bluish sheen with a belly silvery-white. Females have a distinct black blotch surrounded by a golden patch occurring just above the vent. Males have a highly modified anal fin, the third, fourth and fifth rays of which are elongated and thickened to form a 'gonopodium' which is used to inseminate the female."

From CABI (2016):

"The male *Gambusia* is about 35 mm standard length whereas the female is larger (up to 60 mm) with a deeper body, the anal fin unmodified and when pregnant, a gravid spot is visible just above the vent (Lloyd, 1987). The fish are mostly translucent grey with a bluish sheen on their sides with a silver belly (Lloyd, 1987). The fins are colourless, with transverse rows of black spots. Some male Eastern *Gambusia* have irregular black blotching, though some largely

melanistic male individuals exist but are uncommon in their native range (Sterba, 1962) and are absent from Australia (Lloyd, 1987). On the male, the anal fin is modified to form a long, thin intromitent organ, the gonopodium, used for sperm transfer (Lloyd, 1990c). The body is slightly compressed with a large and flattened head. The eyes are large, and the mouth is small and terminal (Lloyd, 1987)."

Biology

From Froese and Pauly (2016b):

"Adults feed on small terrestrial insects usually in the drift and amongst aquatic plants, actively selecting very small prey [Arthington 1989]. Also observed to take in mosquito larvae [Gabrielyan 2001]."

"Matures at 4-6 weeks; 3 generations can be produced in one year. Gestation lasts 3-4 weeks. Brood may reach up to 354 young, but is generally around 40-60 [Riehl and Baensch 1991; Kottelat and Freyhof 2007]."

"Adults occur in standing to slow-flowing water, mostly in vegetated ponds and lakes, backwaters and quiet pools of steams [Page and Burr 1991], typically seen shoaling at the edges [Allen et al. 2002]. They also frequent brackish water [Page and Burr 1991]."

From GISD (2016):

"*Gambusia* is an opportunistic omnivore that feeds on a diverse range of terrestrial insects such as ants and flies that fall on the waters [*sic*] surface as well as aquatic invertebrates including bugs, beetles, fly larvae, zooplankton, filamentous algae and fragments of fruit and other plant tissues. *Gambusia* select their prey according to size, colour, movement and position in water column (Bence and Murdoch 1986; Lloyd 1984; Arthington and Marshall 1999)

Sexual [reproduction]. Internal fertilisation with embryos developing within the female. Livebearer. The reproductive cycle is primarily governed by photoperiod (Pen and Potter, 1991). 50-100 young per brood per female adult. Females have two to three broods per season (Howe 1995).

Individuals become sexually mature in under two months (McDowall 1996). Gestation period is between 21 and 28 days (Cadwallader and Backhouse 1983; McDowall 1996). Female *gambusia* [sic] have the capacity to store sperm from breeding season to breeding season (Howe 1995)."

Human Uses

From GISD (2016):

"Used as a feeder fish for aquarium species. Formerly used to control mosquitoes, but has since been shown to be generally ineffective. Since 1982 the World Health Organisation has no longer recommended the use of *gambusia* [sic] for malaria control purposes and indicates it should not be introduced into new areas."

From CABI (2016):

"*Gambusia* are cited to be used in the commercial aquarium industry (www.fishbase.org) but poor sales are likely given its noxious status in many countries, its aggressive behaviour, and its poor appearance. They are likely to be under aquaculture in the USA for use for mosquito control in rice fields. Mosquito control authorities (councils, health authorities and armed forces) have been known to transfer Eastern *Gambusia* between locations."

Diseases

No data was available on diseases of *Gambusia holbrooki.*

Threat to Humans

From Froese and Pauly (2016b):

"Potential Pest"

3 Impacts of Introductions

From Nico and Fuller (2001):

"According to Courtenay and Meffe (1989), mosquitofish have had the greatest ecological impact by far of any of the introduced poeciliids. Although widely introduced as mosquito control agents, recent critical reviews of the world literature on mosquito control have not supported the view that *Gambusia* are particularly effective in reducing mosquito populations or in reducing the incidence of mosquito-borne diseases (Courtenay and Meffe 1989; Arthington and Lloyd 1989). Because of their aggressive and predatory behavior, mosquitofish may negatively affect populations of small fish through predation and competition (Myers 1967; Courtenay and Meffe 1989). In some habitats, introduced mosquitofish reportedly displaced select native fish species regarded as better or more efficient mosquito control agents (Danielsen 1968; Courtenay and Meffe 1989). Introduced mosquitofish 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). Specific examples of their negative effects include a habitat shift and a reduction in numbers of the threatened Railroad Valley springfish *Crenichthys baileyi* in springs in Nevada (Deacon et al. 1964) and the local elimination of the endangered Sonoran topminnow *Poeciliopsis occidentalis* in Arizona (Moyle 1976; Meffe et al. 1983, Meffe 1985). […] The mosquitofish is also responsible for the elimination of the least chub *Iotichthys phlegethontis* in several areas of Utah (Whitmore 1997). Meffe (1983, 1985) found that mosquitofish are very aggressive, even toward larger fish. They often attack, shred fins, and sometimes kill other species. Mosquitofish are known to prey on eggs, larvae, and juveniles of various fishes, including those of largemouth bass and common carp; they are also known to prey on adults of smaller species (Meffe 1985; Courtenay and Meffe 1989). Courtenay and Meffe (1989) listed impacts on a variety of native fishes."

"Introducing mosquitofish also can precipitate algal blooms when the fish eat the zooplankton grazers (Hurlbert et al. 1972), or in an increase in the number of mosquitoes if the fish eat the invertebrate predators (Hoy et al. 1972). Introduced fishes, including mosquitofish, are likely at

least partially responsible for the decline of the Chiricahua leopard frog *Rana chiricahuensis* in southeastern Arizona (Rosen et al. 1995)."

"Mosquitofish, and other introduced poeciliids, have been implicated in the decline of native damselflies on Oahu, Hawaii. Often the distributions of the damselflies and introduced fishes were found to be mutually exclusive, probably resulting from predation of the fish on the insects (Englund 1999)."

From GISD (2016):

"*Gambusia holbrooki* predate on amphibian eggs; and predate and compete with tadpoles, resulting in injury or death to individuals. They may have a negative influence on some frog species' choice of breeding habitat. *G. holbrooki* have been shown to predate upon the eggs and tadpoles of the 'Critically Endangered (CR)' yellow-spotted tree frog (see *Litoria castanea* in IUCN Red List of Threatened Species); the 'Endangered (EN)' green and gold frog (see *Litoria raniformis* in IUCN Red List of Threatened Species); and the 'Vulnerable (VU)' golden bell frog (see *Litoria aurea* in IUCN Red List of Threatened Species) in Australia (NSW National Parks & Wildlife Service, 2004). *Gambusia* spp. have been implicated in the decline in the range and abundance of native fish species worldwide (Lloyd 1990) through predation and interference competition (McKay 1984; Howe 1995; Ivantsoff and Aarn 1999; Knight 1999). The species is purported to impact on macro-invertebrates such as rotifers, mayflies, beetles, dragonflies and molluscs (Anstis, 2002)."

"Competition: *Gambusia holbrooki* compete for food and space with native fish. They exhibit aggressive behaviour such as fin-nipping that can result in injury and death to fish and tadpoles. Also, fierce competition with native frogs may cause some species to shift breeding habitat to suboptimal habitats.
Predation: *Gambusia holbrooki* predate on amphibian eggs and tadpoles; fish and aquatic macro invertebrates"

From CABI (2016):

"*Gambusia* is highly invasive because of its ability to move and colonise new habitats, its high fecundity, high survival of juveniles and rapid population growth (Moyle and Light, 1996; Williamson and Fitter, 1996; Alemadi and Jenkins, 2007). Eastern *Gambusia* can disperse through waters as shallow as 3 mm, which is only half of average body depth (Alemadi and Jenkins, 2007) and uses drains and natural channels to disperse between water bodies. Rehage and Sih (2004) link dispersal behaviour to the 'invasiveness' of a species, with *G. affinis* dispersing faster than *G. holbrooki* due to the movement of females into new territories. However, other important characteristics, such as fecundity, and maximum population growth rates suggest that *G. holbrooki* is 'a superior invader' (Rehage and Sih, 2004). Eastern *Gambusia* can rapidly increase in population size due to their rapid maturation to breeding age (four weeks in summer) and high survival rate of young (Milton and Arthington, 1983; Lloyd et al., 1986; Lloyd, 1990a)."

"In Australia, and possibly other parts of its introduced range, Eastern *Gambusia* faces few predators, parasites, diseases or competitors (Lloyd, 1987). Experiments have shown that several Australian native fish predators actively avoid eating Eastern *Gambusia* (Lloyd, 1987)."

"Rehage et al. (2005a, b) suggest that invasive species of *Gambusia* (*G. holbrooki* and *G. affinis*) are more efficient foragers than their non-invasive relatives (*G. geiseri* and *G. hispaniolae*), and that invasive juveniles feed more voraciously and widely than adults. This study suggests that *Gambusia*, released from their native habitat and therefore native predators, increase in size, and accordingly, have a higher feeding rate which has a greater impact on native species."

"Many studies in the USA and Australia have found significant habitat overlap between *Gambusia* and native fish throughout all stages of their respective life cycles. These overlaps combined with the superior competitive ability of *Gambusia* mean that native fish may be lost from waters where *Gambusia* dominate (Schoenherr, 1974, 1981; Arthington et al., 1983; Lloyd et al., 1986; Lloyd 1987; Arthington, 1989; Arthington and Lloyd, 1989; Lloyd, 1990; Arthington and Marshall, 1999; Rincon et al., 2002; King, 2003; Pyke, 2005)."

"Eastern *Gambusia* is a voracious predator of invertebrates resulting in a possible increase in mosquito populations, as it targets insects, which are natural predators of mosquitoes. Willems et al. (2005) compared two different fish species on their predation of mosquitoes which found that *Gambusia* were not as effective as controlling mosquito larvae as the native fish in the study. Studies of small native fish and Eastern *Gambusia* diets in the River Murray in South Australia (Lloyd, 1987) showed that Eastern *Gambusia* was a poor predator of mosquito larvae compared to most of the small native fish species. […] Eastern *Gambusia* has been shown, through gut contents assessment, to be significant predators of native fish in Australia (Ivantsoff and Aarn, 1999). It can also have an impact on the tadpoles of native frogs (Sadlier and Pressey, 1994; Morgan and Buttemer, 1996; Komak and Crossland, 2000; Pyke and White, 2000). The reproductive rituals, breeding success and growth of native fishes can be impacted by *gambusia* [sic] (Howe et al., 1997)."

"*Gambusia* occupy the specialized dystrophic habitats of one restricted and two endangered Australian freshwater fishes - *Rhadinocentrus ornatus, Pseudomugil mellis, Nannoperca oxleyana* (all found in South-eastern Queensland). It is possible that *gambusia* [sic] and the three species interact and compete for habitat, food and spawning areas (Howe et al., 1997; Arthington and Marshall, 1999; Knight and Arthington, 2008)."

From Froese and Pauly (2016b):

"Introductions to Europe have seriously threatened many endemic species [Kottelat and Freyhof 2007]. It is now widely accepted that their effect [on mosquito populations] has been minimal and even may have exacerbated the problem due to their voracious appetite for natural invertebrate predators of mosquito larvae [Allen et al. 2002]."

4 Global Distribution

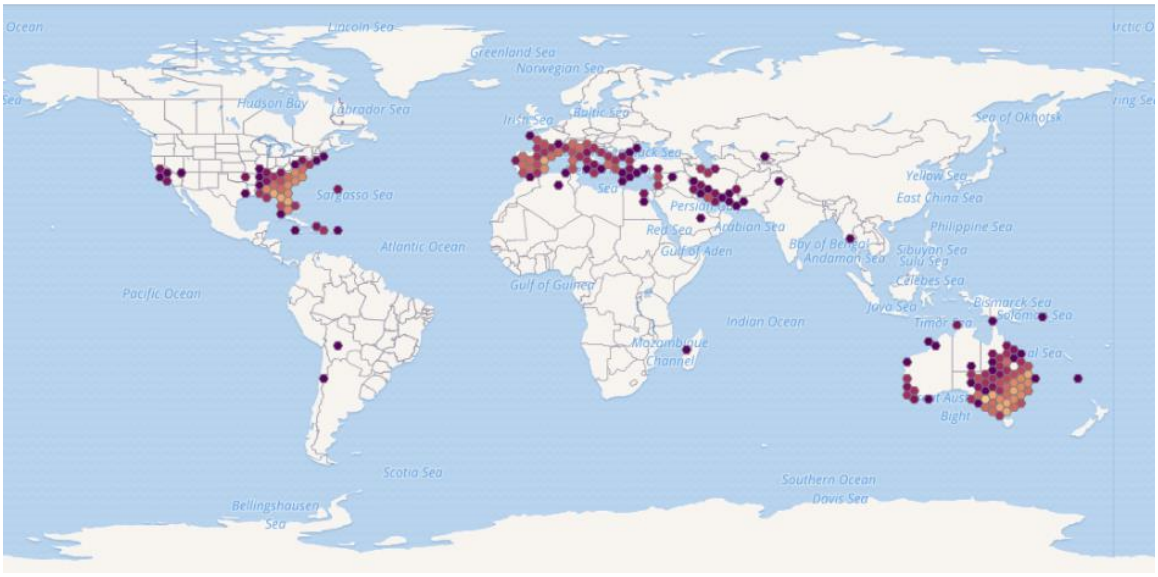

Figure 1. Known global distribution of *Gambusia holbrooki*. Locations are primarily in North America, Europe, Asia, and Australia. Small numbers of observations are in South America and Africa. Map from GBIF Secretariat (2018).

From CABI (2016):

"It is now known that *G. holbrooki* was introduced to Mediterranean Europe and Australia, whereas *G. affinis* was introduced outside its natural range to the western United States, Hawaii, and countries in Africa (Rehage and Sih, 2004)."

Other than the point in Madagascar, all African locations were removed as source points.

There is disagreement over the identification of the species introduced to California, *Gambusia holbrooki* or *G. affinis* (Nico and Fuller 2001). Those points were removed as source points for the climate match.

No mention of *G. holbrooki* in Chile or Bolivia was found in the literature. Those points (Figure 1) were not used as source points in the climate match.

5 Distribution Within the United States

Figure 2. Known distribution of *Gambusia holbrooki* in the United States. Map from Nico and Fuller (2016). The brown shaded area indicates the native range of the species.

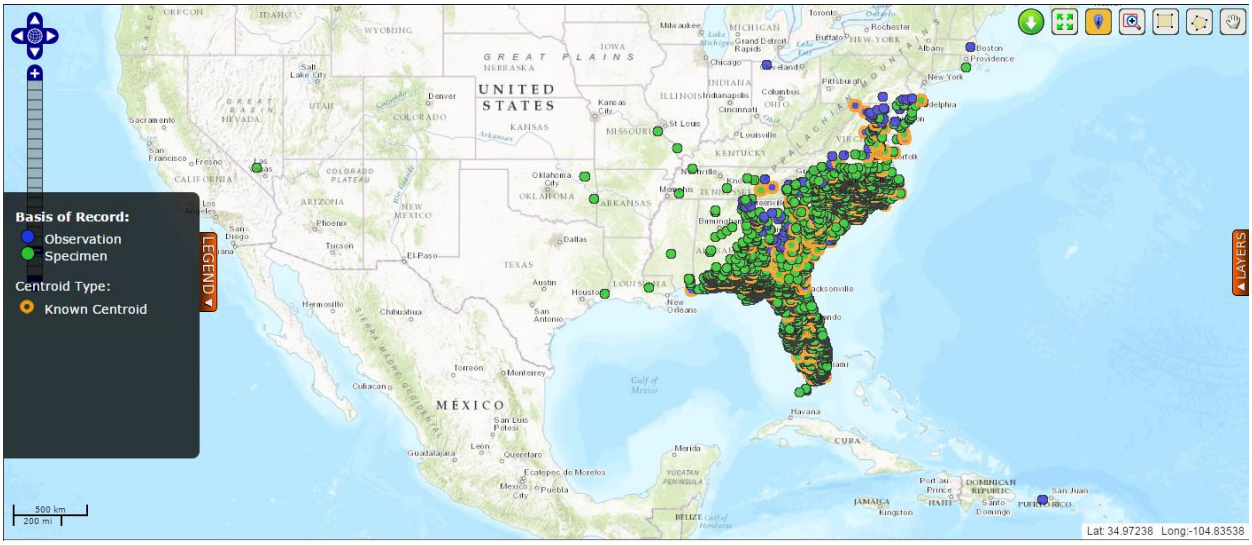

Figure 3. Known distribution of *Gambusia holbrooki* in the United States. Map from BISON (2016).

6 Climate Matching

Summary of Climate Matching Analysis

The climate match for *Gambusia holbrooki* was high in the eastern half of the country and areas of the west. The match was low for the extreme upper Midwest, small pockets of the Great Plains, small portions of Maine, and the Pacific Northwest. It was medium everywhere else. The Climate 6 score (Sanders et al. 2018; 16 climate variables; Euclidean distance) for the contiguous United States was 0.636, high. All states had high individual climate scores except for Colorado, Montana, and Nebraska which had medium scores, and Minnesota, North Dakota, South Dakota, and Wyoming which had low scores.

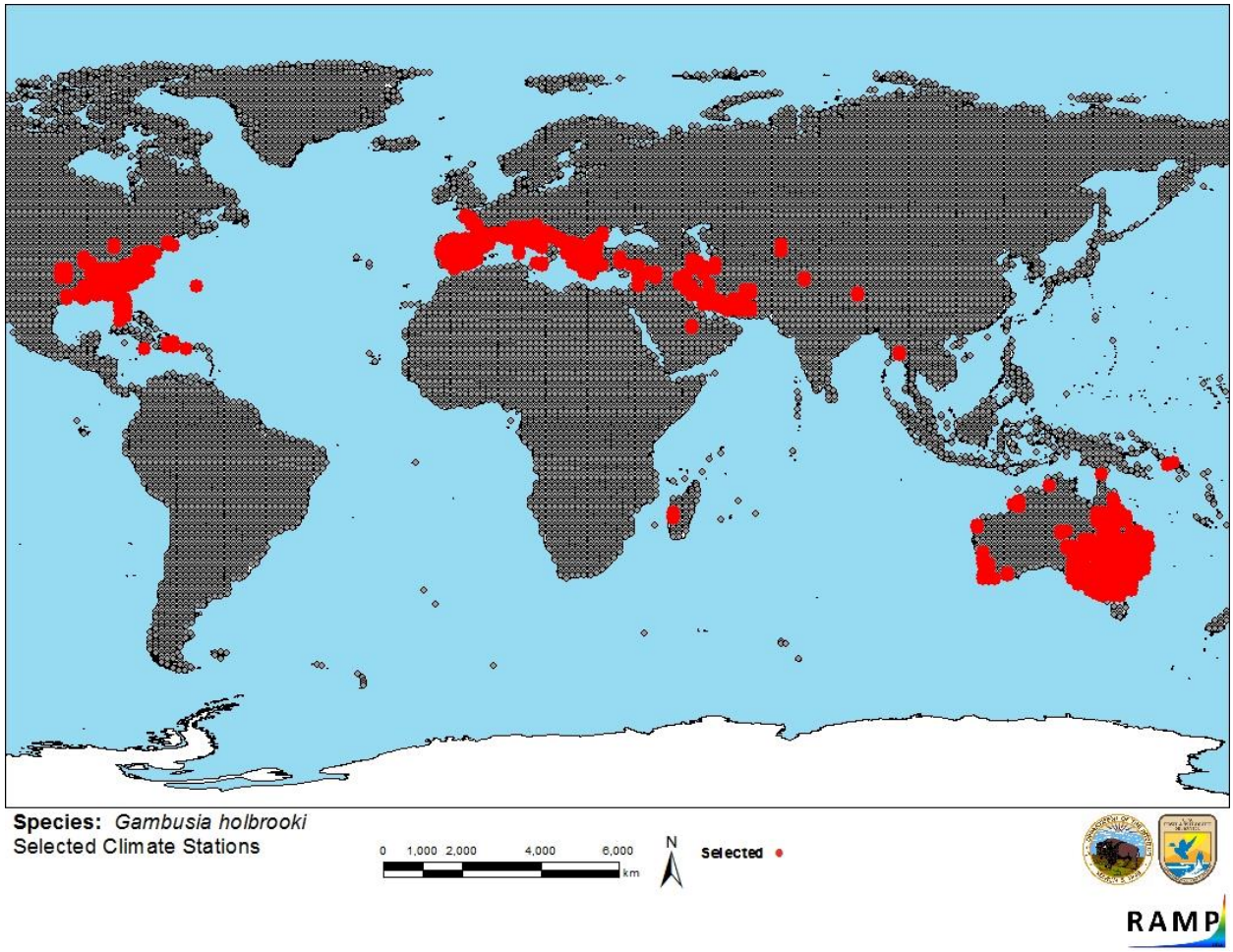

Figure 4. RAMP (Sanders et al. 2018) source map of the world showing weather stations in North America, Europe, Asia, Australia, and Madagascar selected as source locations (red) and non-source locations (gray) for *Gambusia holbrooki* climate matching. Source locations from GBIF Secretariat (2018), BISON (2016), and Nico and Fuller (2016).

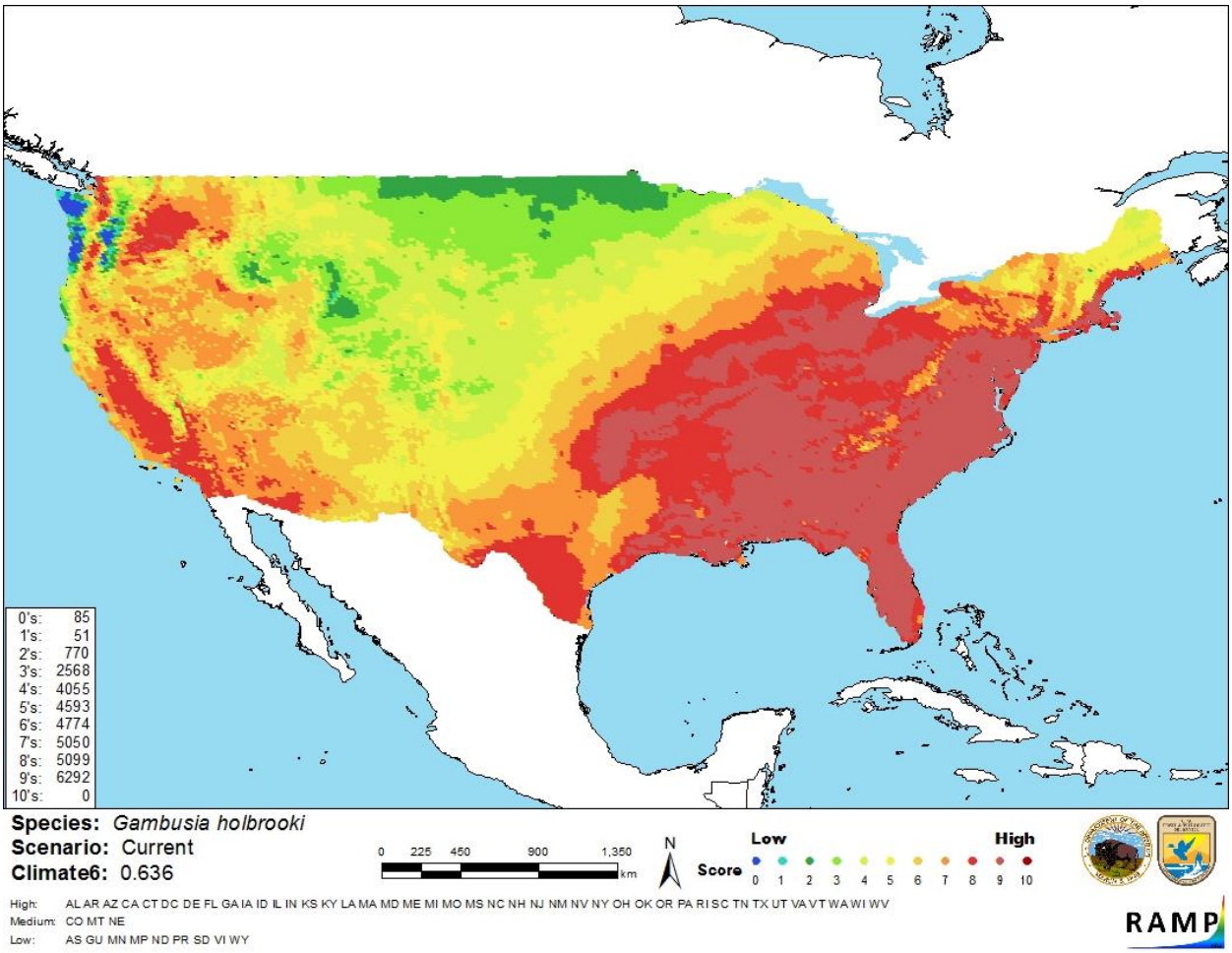

Figure 5. Map of RAMP (Sanders et al. 2018) climate matches for *Gambusia holbrooki* in the contiguous United States based on source locations reported by GBIF Secretariat (2018), BISON (2016), and Nico and Fuller (2016). 0 = Lowest match, 10 = Highest match. Counts of climate match scores are tabulated on the left.

The High, Medium, and Low Climate match Categories are based on the following table:

Climate 6: Proportion of (Sum of Climate Scores 6-10) / (Sum of total Climate Scores)	Climate Match Category
0.000≤X≤0.005	Low
0.005<X<0.103	Medium
≥0.103	High

7 Certainty of Assessment

Certainty of this assessment is high. *Gambusia holbrooki* is a well-known species. Negative impacts from introductions of this species are thoroughly documented in the scientific literature. No further information is needed to evaluate the negative impacts the species is having where introduced.

8 Risk Assessment

Summary of Risk to the Contiguous United States

Eastern Mosquitofish (*Gambusia holbrooki*) is native to the eastern United States. The history of invasiveness of *Gambusia holbrooki* is high. Invasion and establishment of the mosquitofish is occurring in the United States and around the world. Significant adverse impacts are also occurring in invaded waterways and risk of this species moving to new waterways is high. This species has been responsible or partially responsible for negative impacts, including extirpation, on Threatened and Endangered species. The climate match is high, indicating there are suitable areas within the United States for this species to expand into that are outside of the species' native range. The certainty of assessment is high. The overall risk assessment category is high.

Assessment Elements

- **History of Invasiveness (Sec. 3): High**
- **Climate Match (Sec. 6): High**
- **Certainty of Assessment (Sec. 7): High**
- **Remarks/Important additional information** The native range of *Gambusia holbrooki* is wholly within the southeastern United States. Many introductions of this species took place when it was still considered a subspecies of *Gambusia affinis*.
- **Overall Risk Assessment Category: High**

9 References

Note: The following references were accessed for this ERSS. References cited within quoted text but not accessed are included below in Section 10.

BISON. 2016. Biodiversity Information Serving Our Nation (BISON). U.S. Geological Survey. Available: https://bison.usgs.gov. (May 2016).

CABI. 2014. *Gambusia holbrooki* (mosquitofish) [original text by A. Arthington and L. Lloyd]. *In* Invasive Species Compendium. CAB International, Wallingford, UK. Available: http://www.cabi.org/isc/datasheet/82089. (May 2016).

Eschmeyer, W. N., R. Fricke, and R. van der Laan, editors. 2017. Catalog of fishes: genera, species, references. Available: http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp. (October 2017).

FAO (Fisheries and Agriculture Organization of the United Nations). 2016. Database on introductions of aquatic species. FAO, Rome. Available: http://www.fao.org/fi/website/FISearchAction.do. (May 2016).

Froese, R., and D. Pauly, editors. 2016a. FishBase (version Jan 2016). *In* Y. Roskov, L. Abucay, T. Orrell, D. Nicolson, T. Kunze, C. Flann, N. Bailly, P. Kirk, T. Bourgoin, R. E. DeWalt, W. Decock, and A. De Wever, editors. Species 2000 & ITIS Catalogue of Life. Species 2000: Naturalis, Leiden, the Netherlands. Available: http://www.catalogueoflife.org/col/details/species/id/aba63b0655fd06bdbeb4ff233f307ce0. (May 2016).

Froese, R., and D. Pauly, editors. 2016b. *Gambusia boldrooki* Girard, 1859. FishBase. Available: http://www.fishbase.se/summary/Gambusia-holbrooki.html. (May 2016).

GBIF Secretariat. 2018. GBIF backbone taxonomy: *Gambusia holbrooki* Girard, 1859. Global Biodiversity Information Facility, Copenhagen. Available: http://www.gbif.org/species/2350570. (August 2018).

GISD (Global Invasive Species Database). 2016. Species profile: *Gambusia holbrooki*. Invasive Species Specialist Group, Gland, Switzerland. Available: http://issg.org/database/species/ecology.asp?si=617&fr=1&sts=sss&lang=EN. (May 2016).

National Institute for Environmental Studies, Japan. No date. List of regulated living organisms under the Invasive Alien Species Act.

NatureServe. 2016. NatureServe Explorer: An online encyclopedia of life, version 7.1. NatureServe, Arlington, Virginia. Available: http://explorer.natureserve.org. (May 2016).

Nico, L., and P. Fuller. 2001. *Gambusia holbrooki*. U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, Florida. Available: http://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=849. (February 2011).

Nico, L., and P. Fuller. 2016. *Gambusia holbrooki*. U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, Florida. Available: http://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=849. (May 2016).

NOBANIS. 2016. *Gambusia holbrooki*. Available: https://www.nobanis.org/species-info/?taxaId=8729. (December 2016).

Sanders, S., C. Castiglione, and M. Hoff. 2018. Risk assessment mapping program: RAMP, version 3.1. U.S. Fish and Wildlife Service.

10 References Quoted But Not Accessed

Note: The following references are cited within quoted text within this ERSS, but were not accessed for its preparation. They are included here to provide the reader with more information.

Alemadi, S. D., and D. G. Jenkins. 2007. Behavioral constraints for the spread of the eastern mosquitofish, *Gambusia holbrooki* (Poeciliidae). Biological Invasions (2008)10:59.

Allen, G. R., H. Midgley, and M. Allen. 2002. Field guide to the freshwater fishes of Australia. Western Australian Museum, Perth, Western Australia.

Anstis, M. 2002. Tadpoles of South-eastern Australia: a guide with keys. New Holland Publishers, Sydney, Australia.

Arthington, A. H. 1989. Diet of *Gambusia affinis holbrooki*, *Xiphophorus helleri*, *X. maculatus*, and *Poecilia reticulata* (Pisces: Poeciliidae) in streams of southeastern Queensland, Australia. Asian Fisheries Science 2:193–212.

Arthington, A. H., S. Hamlet, and D. R. Bluhdorn. 1990. The role of habitat disturbance in the establishment of introduced warm-water fishes in Australia. Pages 61–66 *in* D. A. Pollard, editor. Introduced and translocated fishes and their ecological effect. Australian Government Publishing Service, Canberra.

Arthington, A. H., and L. N. Lloyd. 1989. Introduced poeciliids in Australia and New Zealand. Pages 333–348 *in* G. K. Meffe, and F. F. Snelson, Jr., editors. Ecology and evolution of livebearing fishes (Poeciliidae). Prentice Hall, Englewood Cliffs, New Jersey.

Arthington, A. H., and C. J. Marshall. 1999. Diet of the exotic mosquitofish, *Gambusia holbrooki*, in an Australian lake and potential for competition with indigenous fish species. Asian Fisheries Science 12:1–16.

Arthington, A. H., D. A. Milton, and R. J. McKay. 1983. Effects of urban development and habitat alterations on the distribution and abundance of native and exotic freshwater fish in the Brisbane region, Queensland. Australian Journal of Ecology 8:87–101.

Bence, J. R., and W. W. Murdoch. 1986. Prey selection by the mosquitofish: relation to optimal diet theory. Ecology 67(2):324–336.

Boschung, H. T. 1992. Catalog of freshwater and marine fishes of Alabama. Bulletin of the Alabama Museum of Natural History 14:1–266.

Cadwallader, P. L., and G. N. Backhouse. 1983. A guide to the freshwater fish of Victoria. Victoria Government Printing Office. Melbourne, Australia.

Chapman, P., and K. Warburton. 2006. Postflood movements and population connectivity in gambusia (*Gambusia holbrooki*). Ecology of Freshwater Fish 15:357–365.

Courtenay, W. R., Jr., and G. K. Meffe. 1989. Small fishes in strange places: a review of introduced poeciliids. Pages 319–331 *in* G. K. Meffe, and F. F. Snelson, Jr., editors. Ecology and evolution of livebearing fishes (Poeciliidae). Prentice Hall, Englewood Cliffs, New Jersey.

Danielsen, T. L. 1968. Differential predation on *Culex pipiens* and *Anopheles albimanus* mosquito larvae by two species of fish (*Gambusia affinis* and *Cyprinodon nevadensis*) and the effects of simulated reeds on predation. Doctoral dissertation. University of California, Riverside.

Deacon, J. E., C. Hubbs, and B. J. Zahuranec. 1964. Some effects of introduced fishes on the native fish fauna of southern Nevada. Copeia 1964:384–388.

Dill, W. A., and A. J. Cordone. 1997. History and status of introduced fishes in California, 1871–1996. California Department of Fish and Game Fish Bulletin 178.

Englund, R. A. 1999. The impacts of introduced poeciliid fish and Odonata on the endemic Megalagrion (Odonata) damselflies of Oahu Island, Hawaii. Journal of Insect Conservation 3:225–243.

Fowler, H. W. 1952. A list of the fishes of New Jersey, with off-shore species. Proceedings of the Academy of Natural Sciences of Philadelphia CIV:89–151.

Gabrielyan, B. K. 2001. An annotated checklist of freshwater fishes of Armenia. Naga, The ICLARM Quarterly 24(3–4):23–29.

Galat, D. L., and B. Robertson. 1992. Response of endangered *Poeciliopsis occidentalis sonoriensis* in the Rio Yaqui drainage, Arizona, to introduced *Gambusia affinis*. Environmental Biology of Fishes 33:249–264.

Haynes, J. L. 1983. Annual reestablishment of mosquitofish in Nebraska. Copeia 1983(1):232–235.

Hernandez-Martich, J. D., and M. H. Smith. 1990. Patterns of genetic variation in eastern mosquitofish (*Gambusia holbrooki* Girard) from the Piedmont and Coastal Plain of three drainages. Copeia 1990(3):619–630.

Howe, E. H. I. 1995. Studies in the biology and reproductive characteristics of *Pseudomugil signifer*. Doctoral dissertation. University of Technology, Sydney, Australia.

Howe, E., C. Howe, R. Lim, and M. Burchett. 1997. Impact of the introduced poeciliid *Gambusia holbrooki* (Girard, 1859) on the growth and reproduction of *Pseudomugil signifer* (Kner, 1865) in Australia. Marine and Freshwater Research 48(5):425–433.

Hoy, J. B., E. E. Kaufmann, and A. G. O'Berg. 1972. A large-scale field test of *Gambusia affinis* and Chlorpyrifos for mosquito control. Mosquito News 32(2):163–171.

Hubbs, C. L., and K. F. Lagler. 1958. Fishes of the Great Lakes region. University of Michigan Press, Ann Arbor.

Hurlbert, S. H., J. Zedler, and D. Fairbanks. 1972. Ecosystem alteration by mosquitofish (*Gambusia affinis*) predation. Science 175:639–641.

Ivantsoff, W., and Aarn. 1999. Detection of predation on Australian native fishes by *Gambusia holbrooki*. Marine and Freshwater Research 50:467–8.

Jenkins, R. E., and N. M. Burkhead. 1994. Freshwater fishes of Virginia. American Fisheries Society, Bethesda, Maryland.

King, A. 2003. Niche overlap between larvae of exotic and native fish in a lowland river. Presented at the "ASFB Invasive species: Fish and Fisheries Workshop", Australian Society for Fish Biology, Wellington, New Zealand.

Knight, J. T. 1999. Density dependent interference competition between the Australian native fish *Pseudomugil signifer* (Kner, 1865) and the introduced Poeciliid *Gambusia holbrooki* (Girard, 1859). Integrated project prepared as partial fulfilment of the requirements of the Bachelor of Applied Science. Fisheries and Aquaculture Management, Southern Cross University, Australia.

Knight, J. T., and A. H. Arthington. 2008. Distribution and habitat associations of the endangered Oxleyan pygmy perch, *Nannoperca oxleyana* Whitley, in eastern Australia. Aquatic Conservation Marine and Freshwater Ecosystems.

Komak, S., and M. Crossland. 2000. An assessment of introduced mosquitofish (*Gambusia affinis holbrooki*) as a predator of eggs, hatchlings, and tadpoles of native and non-native anurans. Wildlife Research 27:185–189.

Kottelat, M., and J. Freyhof. 2007. Handbook of European freshwater fishes. Publications Kottelat, Cornol, Switzerland.

Krumholz, L. A. 1948. Reproduction in the western mosquitofish, *Gambusia affinis affinis* (Baird & Girard), and its use in mosquito control. Ecological Monographs 18(1):1–43.

Lintermans, M. 2004. Human-assisted dispersal of alien freshwater fish in Australia. New Zealand Journal of Marine and Freshwater Research 38:481–501.

Lloyd. 1984. [Source material did not give full citation for this reference.]

Lloyd, L. N. 1987. Ecology and distribution of the small native fish of the lower River Murray, South Australia and their interactions with the exotic mosquitofish, *Gambusia affinis holbrooki* (Girard). Department of Zoology, University of Adelaide, Australia.

Lloyd, L. N. 1990. Ecological interactions of *Gambusia holbrooki* with Australian native fishes. Pages 94–97 *in* D. A. Pollard, editor. Introduced and translocated fishes and their ecological effect. Australian Government Publishing Service, Canberra.

Lloyd, L. N. 1990. Taxonomic update - species control using taxonomy - *Gambusia affinis* no longer exists in Australia. Australian Fish Biology Newsletter 20(2).

Lloyd, L. N., A. H. Arthington, and D. A. Milton. 1986. The mosquitofish - a valuable mosquito control agent or a pest? *In* Kitching, editor. The ecology of exotic plants and animals: some Australian case studies. John Wiley and Sons, Brisbane, Australia.

Lloyd, L. N., and J. F. Tomasov. 1985. Taxonomic status of the mosquitofish *Gambusia affinis* (Poeciliidae), in Australia. Australian Marine and Freshwater Research 36:447–51.

Lydeard, C., and M. C. Wooten. 1991. Occurrence of *Gambusia affinis* in the Savannah and Chattahoochee drainages: previously undescribed geographic contacts between *G. affinis* and *G. holbrooki*. Copeia 1991:1111–1116.

Lynch, J. D. 1988b. Habitat utilization by an introduced fish, *Gambusia affinis*, in Nebraska (Actinopterygii: Poeciliidae). Transactions of the Nebraska Academy of Sciences 16:63–67.

McDowall, R. M. 1996. Freshwater fishes of south-eastern Australia. Reed Books, Chatswood, New South Wales, Australia.

McDowall, R. M. 1996. Family Poeciliidae: Livebearers. Page 247 *in* R. M. McDowall, editor. Freshwater fishes of south-eastern Australia. Reed Books, Chatswood, New South Wales, Australia.

McKay, R. J. 1984. Introductions of exotic fishes in Australia. *In* W. R. Courtenay, and J. R. Stauffer, editors. Distribution, biology and management of exotic fishes. John Hopkins University Press, Baltimore, Maryland.

Meffe. 1983. [Source material did not give full citation for this reference.]

Meffe, G. K. 1984. Effects of abiotic disturbance on coexistence of predator-prey fish species. Ecology 65:1525–1534.

Meffe, G. K. 1985. Predation and species replacement in American southeastern fishes: a case study. Southwestern Naturalist 30:173–87.

Meffe, G. K., D. A. Hendrickson, and W. L. Minckley. 1983. Factors resulting in decline of the endangered Sonoran topminnow *Poeciliopsis occidentalis* (Atheriniformes: Poeciliidae) in the United States. Biological Conservation 25:135–159.

Merrick, J. R., and G. E. Schmida. 1984. Australian freshwater fishes: biology and management. Griffen Press, Adelaide, Australia.

Milton, D. A., and A. H. Arthington. 1983. Reproductive biology of *Gambusia affinis holbrooki* Baird and Girard, *Xiphophorus helleri* (Gunther) and *X. maculatus* (Heckel) (Pisces; Poeciliidae) in Queensland, Australia. Journal of Fish Biology 23(1):23–41.

Morgan, L. A., and W. A. Buttemer. 1996. Predation by the non-native fish *Gambusia holbrooki* on small *Litoria aurea* and *L. dentata* tadpoles. Australian Zoologist 30(2):143–149.

Moyle, P. B. 1976. Inland fishes of California. University of California Press, Berkeley.

Moyle, P. B., and L. Light. 1996. Biological invasions of fresh water: empirical rules and assembly theory. Biological Conservation 78:149–161.

Myers, G. S. 1967. *Gambusia*, the fish destroyer. Australian Zoology 13(2):102.

NSW (New South Wales) National Parks & Wildlife Service. 2004. Predation by the plague minnow (*Gambusia holbrooki*) - key threatening process declaration. Available: http://www.nationalparks.nsw.gov.au/npws.nsf/Content/Predation+by+the+plague+minnow+Gambusia+holbrooki+key+threatening+process+declaration. (January 2005).

Page, L. M., and B. M. Burr. 1991. A field guide to freshwater fishes of North America north of Mexico. The Peterson Field Guide Series, volume 42. Houghton Mifflin, Boston.

Pen, L. J., and I. C. Potter. 1991. Reproduction, growth and diet of *Gambusia holbrooki* (Girard) in a temperate Australian river. Aquatic Conservation: Marine and Freshwater Ecosystems 1:159–172.

Pflieger, W. L. 1997. The fishes of Missouri. Missouri Department of Conservation, Jefferson City.

Pyke, G. H. 2005. A review of the biology of *Gambusia affinis* and *G. holbrooki*. Reviews in Fish Biology and Fisheries 15(4):339–365.

Pyke, G. H., and A. W. White. 2000. Factors influencing predation on eggs and tadpoles of the endangered green and golden bell frog *Litoria aurea* by the introduced plague minnow *Gambusia holbrooki*. Australian Zoologist 31(3):496–505.

Rauchenberger, M. 1989. Systematics and biogeography of the genus *Gambusia* (Cyprinodontiformes: Poecilidae). American Museum Novitates (2951):1–74.

Rehage, J. S., and A. Sih. 2004. Dispersal behaviour, boldness, and the link to invasiveness: a comparison of four *Gambusia* species. Biological Invasions 6:379–391.

Rehage, J. S., B. K. Barnett, and S. Sih. 2005a. Behavioural responses to a novel predator and competitor of invasive mosquitofish and their non-invasive relatives (*Gambusia* sp.). Behavioural Ecology and Sociobiology 57:256–266.

Rehage, J. S., B. K. Barnett, and A. Sih. 2005b. Foraging behaviour and invasiveness: do invasive *Gambusia* exhibit higher feeding rates and broader diets than their noninvasive relatives? Ecology of Freshwater Fish 14:352–360.

Riede, K. 2004. Global register of migratory species - from global to regional scales. Final Report of the R&D-Projekt 808 05 081. Federal Agency for Nature Conservation, Bonn.

Riehl, R., and H. A. Baensch. 1991. Aquarien atlas. Band. 1. Melle: Mergus, Verlag für Natur- und Heimtierkunde, Germany.

Riehl, R., and H. A. Baensch. 1996. Aquarien atlas, Band 1, 10th edition. Mergus Verlag GmBH, Melle, Germany.

Rincon, P. A., A. M. Correas, F. Morcillo, P. Risueno, and J. Lobon-Cervia. 2002. Interactions between the introduced eastern mosquitofish and two autochthonus Spanish toothcarps. Journal of Fish Biology 61:1560–1585.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1991. Common and scientific names of fishes from the United States and Canada. American Fisheries Society, Special Publication 20, Bethesda, Maryland.

Rosen, P. C., C. R. Schwalbe, D. A. Parizek, Jr., P. A. Holm, and C. H. Lowe. 1995. Introduced aquatic vertebrates in the Chiricahua region: effects on declining native ranid frogs. Pages 251–261 *in* Biodiversity and management of the Madrean Archipelago: the sky islands of southwestern United States and northwestern Mexico.

Sadlier, R. A., and R. L. Pressey. 1994. Reptiles and amphibians of particular conservation concern in the western division of New South Wales: a preliminary review. Biological Conservation 69:41–54.

Schoenherr, A. A. 1974. Life history of the topminnow *Poecilliposis occidentalis* (Baird and Girard) in Arizona and an analysis of its interaction with the mosquitofish (*G. affinis*). Arizona State University, Tempe.

Schoenherr, A. A. 1981. The role of competition in the replacement of native fishes by introduced species. Pages 173–203 *in* R. S. Naiman, and D. L. Stolz, editors. Fishes in North American deserts.

Seal, W. P. 1910. Fishes in their relation to the mosquito problem. Paper presented before the Fourth International Fishery Congress held at Washington, 1908. Bulletin of the Bureau of Fisheries 28(683):831–838.

Shapovalov, L., A. J. Cordone, and W. A. Dill. 1981. A list of freshwater and anadromous fishes of California. California Fish and Game 67(1):4–38.

Sterba, G. 1962. Freshwater fishes of the world. Vista, London.

Swift, C. C., T. R. Haglund, M. Ruiz, and R. N. Fisher. 1993. The status and distribution of the freshwater fishes of southern California. Bulletin of the Southern California Academy of Sciences 92(3):101–167.

Whitmore, S. 1997. Aquatic nuisance species in Region 6 of the Fish and Wildlife Service. U.S. Fish and Wildlife Service, Great Plains Fish and Wildlife Management Assistance Office, Pierre, South Dakota.

Willems, K. J., C. E. Webb, and R. C. Russell. 2005. A comparison of mosquito predation by the fish *Pseudomugil signifier* Kner and *Gambusia holbrooki* (Girard) in laboratory trials. Journal of Vector Ecology 30(1):87–90.

Williamson, M. H., and A. Fitter. 1996. The characteristics of successful invaders. Biological Conservation.

Woodling, J. 1985. Colorado's little fish: a guide to the minnows and other lesser known fishes in the state of Colorado. Colorado Division of Wildlife, Denver.

Wooten, M. C., K. T. Scribner, and M. H. Smith. 1988. Genetic variability and systematics of *Gambusia* in the southeastern United States. Copeia 1988(2):283–289.