World War II and the rise of the plague minnow *Gambusia holbrooki* (Girard, 1859) in Australia

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ABSTRACT

The Plague Minnow *Gambusia holbrooki* (Girard, 1859) was first introduced into Australian waters in 1925. Early introductions were carried out in Sydney, Melbourne, Brisbane, and later Perth, by government agencies in an attempt to reduce the incidence of mosquitoes in the capital cities. *G. holbrooki* flourished, but no reports were made of any apparent ecological problems arising from its introduction.

World War II and the advent of the war in the Pacific resulted in heavy Allied troop movements between mainland Australia, New Guinea and the Pacific Islands. Malaria began to take a heavy toll, so the US Army instigated a means of mosquito control through the captive-breeding and introduction of the Western Gambusia *G. affinis* (Baird and Girard, 1853) throughout the south-west Pacific region. The Australian Army initiated a similar campaign using the already-available *G. holbrooki* to establish gambusia in creeks and wetlands near military bases and hospitals in eastern Australia. The Australian Army Malaria Unit was deployed to develop gambusia breeding ponds and to disperse the fish to suitable sites. Other methods of mosquito control were also employed.

By the end of WW II *G. holbrooki* was widely established throughout many parts of eastern Australia, but the program of captive breeding and release remained in place for several more years as many malaria-affected personnel were now resident in Australia. In the early 1960s the first reports of adverse environmental impacts of gambusia on native fish populations appeared, and these were quickly followed by reports of impacts on other organisms, such as frogs. Gambusia was always likely to become an environmental pest species once introduced into Australia. The need to control mosquitoes and mosquito-borne diseases during and following WW II was paramount, however, and efforts to do this greatly accelerated the spread of gambusia. The fish established in high densities in areas where undesirable environmental consequences later became apparent, precipitating the disaster for wildlife that we see today.

Key words: Gambusia, ecological, disaster, Australia, WWII

Introduction

In Australia since European settlement the impacts of exotic invasive species on native fauna populations have been widespread, often disastrous for individual species or populations, and frequently poorly documented (Low 1999). This paper describes the widespread introductions of the Plague Minnow or Eastern Gambusia *Gambusia holbrooki* (Girard, 1859) in Australia, beginning with the reasons for the introductions, traces the history of gambusia introductions both in Australia and in other parts of the world, and examines the negative environmental results of the spread of gambusia in Australian waterways. In this publication dedicated to ecological disasters, the gambusia story in Australia is both classic and salutary. The initial introduction of this fish was permitted with complete disregard for any subsequent environmental consequences, and its facilitation during WW II was deemed necessary as part of the war effort and was carried out of a time when it was not possible to consider the wider ramifications of its spread. Finally, the story of gambusia in Australia demonstrates how the ill-considered actions of one generation handicap the efforts of later generations to attain environmental sustainability.

Background to an ecological disaster

Mosquito-borne diseases

Mosquitoes are vectors for a large number of major global diseases (Table 1), particularly yellow fever and malaria (Weatherall *et al.* 1987). Mosquitoes are estimated to transmit disease to more than 700 million people annually in Africa, South America, Central America, Mexico and much of Asia, with millions of deaths resulting (Crosby 2005).

Despite the high infection rates and high mortalities resulting from infection, the role of mosquitoes in transferring pathogens was only established relatively recently. Pioneering work conducted by Reed, Gorgas and others in the early 1900s demonstrated that yellow fever and malaria in Cuba and the Panama Canal Zone were spread by pathogens present in the saliva acquired from the bite of mosquitoes (McCullough 1977).

Yellow fever epidemics were common prior to the end of the 19th century. French engineers commenced the construction of the Panama Canal in 1880 but were thwarted by a spiraling death toll: 21,900 labourers lost their lives during these yellow fever epidemics. During the Spanish-American War of 1898, yellow fever outbreaks

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Table 1. Mosquito-borne diseases (after Cook 1996)

Taxon	Pathogen	Disease
Protozoa	Plasmodium	Malaria
Nematoda	Filariidae	Elephantiasis
Virus	Bunyaviridae	Arbovirus encephalitides: La Crosse encephalitis; California encephalitis. Viral hemorrhagic fever: Rift Valley fever
	Flaviviridae	Arbovirus encephalitides: Japanese encephalitis; Australian [Murray Valley] encephalitis; St. Louis encephalitis; West Nile fever.
		Viral hemorrhagic fevers: dengue fever; yellow fever; Zika fever
	Togaviridae	Arbovirus encephalitides: eastern equine encephalomyelitis; western equine encephalomyelitis; Venezuelan equine encephalomyelitis.
		Chikungunya
		O'Nyong-nyong fever
		Ross River fever

prompted the US Surgeon General to send a medical team headed by Walter Reed to investigate the cause. Reed was later able to prove that yellow fever was transmitted by the mosquito *Aedes aegypti*. The realization of the role of mosquitoes as the vectors of yellow fever enabled the completion of the Panama Canal. American engineers took over the construction of the canal from the French and introduced novel management practices to combat mosquitoes: stagnant water pools near the work camps were drained or dosed with chemicals (such as kerosene or diesel) and workers were forced to use bed nets at night. Once mosquito numbers had been controlled and the incidence of infection reduced, worker death rates fell dramatically and work was completed on the construction of the Panama Canal in 1914 (McCullough 1977).

Methods of mosquito control

The early 1900s marked the first time that fish were integrated into the biological control of the aquatic larval stages (wrigglers) of mosquitoes. New Jersey, in the USA, was once called the "Mosquito State" because of the swarms of mosquitoes that infested the numerous estuaries dotting its shores. The introduction of *G. affinis* in New Jersey in 1905 (Smith 1908) was hailed as being so successful that this fish was subsequently introduced worldwide as the most cost-effective means of controlling mosquitoes (Meisch 1985). In the early 1900s, it was not known that two species of *Gambusia* occurred in the USA: *Gambusia affinis* (Figure 1), now known as the Western Gambusia, and *G. holbrooki*, the Eastern Gambusia (Figure 2). Together these two species of fish are called Plague Minnows, Top Minnows or Mosquitofish and are now the most widely distributed species of fish in the world (Pyke 2005). They have been transported and have established on every continent except Antarctica (Krumholz 1948). Gambusia releases are still carried out today in the USA for military (Scholdt *et al.* 1972) and civilian (Ken *et al.* 1994) purposes.

Figure 1. Male (smaller) and female *Gambusia affinis.*

Figure 2. Female *Gambusia holbrooki.*

While gambusia were used as the simplest method of controlling mosquito larvae, chemical methods were later applied to control adult mosquito numbers. DDT was the most widespread of these chemicals. It was first synthesized in 1874, but its insecticidal properties were not discovered until 1939. DDT was used with great success in the second half of World War II to limit the infection rates of malaria and typhus among civilians and troops. After the war, DDT was used as an agricultural insecticide, and soon its production and use became even more widespread (Sharma 2003). Unfortunately, as was discovered later, DDT (and many other pesticides) was responsible for producing malignant cancers and birth defects in unborn children, and its use was banned in the USA in 1972. DDT was subsequently banned for agricultural use worldwide under the Stockholm Convention, but limited, controversial use in disease vector control continues in some poorer countries (Curtis 1994).

The main method of controlling adult mosquitoes in residential areas in Central and South America has been by spraying the inside surfaces of the walls and ceilings of houses with a residual insecticide. The insecticide most widely used for house spraying was DDT, which has continued to be recommended for this purpose long after it was banned for agricultural use in the USA and many other countries. It remained as a recommended insecticide because of its relative cheapness and its durability. Houses needed to be sprayed only once or twice a year (Collins and Paskewitz 1995). The eventual widespread ban on DDT meant that DDT was replaced by organophosphate or carbamate insecticides such as malathion or bendiocarb. DDT was also replaced in countries such as Sri Lanka, parts of India, Pakistan, Turkey and parts of Central America where DDT resistance in mosquitoes had been detected. However, other insecticides are considerably more expensive to use than DDT, and malathion does not persist well on mud walls (Curtis 1991). Pyrethroids, such as deltamethrin and lambdacyhalothrin, are effective in mosquito control at far lower application rates than DDT but they are still more expensive than DDT per house protected per year (Curtis 1994).

An increasingly popular application of pyrethroids is in the impregnation of bed nets (Curtis 1991). Nets have long been appreciated as a protection against night-biting mosquitoes, including malaria vectors. However, nets are often torn or hung incorrectly so that mosquitoes can enter or bite through them. Bed nets were impregnated with an insecticide that was safe for close human contact to add a chemical barrier to the imperfect physical barrier created by the net. Pyrethroid impregnation of holed bed nets makes them function much better in mosquito control, apparently because a treated net kills or irritates and repels mosquitoes before they have found a hole in the net and entered through it (Hualiu *et al.* 1995).

The spread of Gambusia around the world

In the United States the first known introductions of gambusia took place in the early 1900s (Krumholz 1948). In 1905 *G. affinis*, reportedly sourced from North Carolina, was released into New Jersey waters for the purpose of controlling mosquitoes (Krumholz 1948). Also in 1905, about 150 *G. affinis* were introduced into Hawaii from Texas to test their effectiveness in preying on mosquito larvae (Seale 1917), and by 1910 their descendants had been released into parts of Oahu, Hawaii, Maui, Kauai, and Molokai (Stearns 1983). The results of these early trials using gambusia paved the way for further introductions across large areas of the USA over the next forty years by organizations such as the former U.S. Public Health Service (Krumholz 1948).

The apparent success of gambusia in reducing mosquito numbers in the USA, Cuba and Panama appeared to herald a world-wide solution for mosquito control. Gambusia were easy to breed, tolerant of a range of aquatic conditions and temperatures and could be easily transported over large distances (Pyke 2005). Gambusia appeared to be the logical tool in waging the global war on mosquitoes, and the fish was specifically promoted as a cheap and effective way to control mosquitoes, and the most practical way to reduce the spread of diseases such as yellow fever and malaria (Rockerfeller Foundation 1921).

The Western Gambusia (*G. affinis*) is the most widely distributed species of fish in the world. It was translocated many times after 1905 (Table 2) and was still being translocated between countries as late as 1982 (Courtenay and Meffe 1989). In contrast, the Eastern Gambusia (*G. holbrooki*) came to Australia from Georgia (USA) via Italy in 1925 (Lloyd and Tomasov 1985) and has been less widely dispersed.

Table 2. The history of the spread of *Gambusia affinis* 1905-1939 (after Tomasov 1981)

Year	Source Country/ Region	Recipient Country/ Region
1905	USA (Texas)	Hawaii
1914	USA	Puerto Rico, Mexico
1919-1921	USA	Italy
1920	USA	Turkey
1920-1924	USA	Taiwan, Philippines
1921	Italy	Spain, Portugal, Romania
1924	USA	Canada
1924	USA	France, Israel
1925	USA	Zimbabwe
1925	Italy	Russia
1927	Philippines	China
1928	Italy	India, Egypt
1929	Italy	Sudan, Morocco, Indonesia
1930	Italy	Uzbekistan, Germany, other parts of Europe
1930	Unknown	Papua New Guinea
1930	Hawaii	New Zealand
1931	Russia	Kazakhstan, Afghanistan
1935	Zimbabwe	Central Africa
1936	Central Africa	South Africa
1937	Unknown	Chile
1939	Mexico	Central America

The introduction of *Gambusia holbrooki* to Australia

Because of its declared ability to control mosquitoes, *Gambusia holbrooki* was imported into Australia under the aegis of state government health agencies. The first shipment of fish was consigned to the Botanic Gardens in Sydney from Italy in 1925 (Black 1972). Shortly afterwards, further consignments of *G. holbrooki* were received by the Brisbane City Council and these fish were released into many of the creeks and wetlands in the Greater Brisbane area over the next six years. During the 1930s Brisbane City Council established a hatchery in South Brisbane to breed and release these fishes believed to be voracious consumers of mosquito larvae. In the hatchery were bred large numbers of *G. holbrooki* and the guppy *Lebistes reticulatus* (Thomson 1978).

The Brisbane releases were the most extensive in Australia at the time and dwarfed subsequent releases that were made in Perth and Sydney. Other releases were carried out by the Australian Army but these were confined to areas near military bases; for example, a release was carried out in 1931 at Alice Springs (Arthington *et al.* 1986).

The Sydney City Health Officer acquired an additional 200 *G. holbrooki* from Italy in the early 1930s and released them in several sites around Sydney. Twelve individuals from this release were subsequently re-caught and translocated to a pond in Newcastle (Moore 1973). A survey of the Newcastle area in 1939 was carried out by health officials and found a large number of places where mosquitoes could breed around the city. Beginning in 1942 countless *G. holbrooki* were bred and liberated in the Newcastle area (Moore 1973). Gambusia were introduced into New Guinea (*G. affinis*) in the early 1930s and to Cairns and several other parts of tropical Australia (*G. holbrooki*) in the late 1930s (Arthington *et al.* 1986).

Gambusia were first liberated in Western Australia in 1934 when an amateur fish breeder released *G. holbrooki* in irrigation ditches at Nedlands, Perth. Subsequent to this release, Western Australian public services such as local health councils carried out gambusia introductions across the state; these were done without referral to the Western Australian Department of Fisheries and Wildlife or other government agencies (Mees 1977).

With such greatly assisted dispersal, gambusia were able to quickly establish viable populations at most of the release sites. Despite the elevated abundance of gambusia in Australia at this time, no adverse environmental effects were reported (Pyke 2005).

WW II and the war in the Pacific

In the 1930s the threat of war with Japan became imminent. When Japanese forces moved across the Pacific in the early 1940s, the small Allied military presence in north Queensland was intensified. The Australian Army had begun investigating areas of north Queensland for strategic military sites in the late 1930s, but when war was declared on Japan on 9 December 1941, the construction of military installations began in earnest. The bombing of Darwin (March 1942) and Townsville (July 1942), and the arrival of American troops in the north (from March 1942) added further impetus to the establishment of facilities in this area. When hostilities extended to Papua New Guinea in May 1942, the military presence in the north of Australia escalated to maximum capacity (Stanley 2008).

The war in the Pacific reached its peak in 1942; vast armadas of Allied warships plied the southwest Pacific in an effort to repel the Japanese advance. Battle fronts were established in Singapore, New Guinea and many of the Pacific islands. Many soldiers from both sides lost their lives to malaria. The US Army undertook a massive stocking campaign using Western Gambusia, and introduced this fish into many of the Pacific Islands such as Yap, Guam, the Marshall Islands, Midway and the Philippines (Scholdt *et al.* 1972).

In Australia, the Army Malaria Control Unit was formed and its task was to deal with the influx of malaria-affected soldiers. Two major army hospitals were established to receive these patients; near Cairns (Rocky Creek Hospital), and in Brisbane (Ennogera). With so many war personnel entering Australia that were carrying the malaria parasite, the risk of a malaria outbreak among the general community was high. To protect the community, a more effective mosquito control program was urgently required.

Following the American Army's lead, the Australian Army established several mosquito control measures including the use of quinine, non-military housing, construction of bases close to the coast, and the clearance of vegetation around army barracks to maximize sea breezes to repel and disperse adult mosquitoes (Ford 1950; Spencer 1992).

In Australia, the Malaria Control Unit established gambusia breeding ponds in Queensland (where the fish was relatively common already) and the unit was then employed in dispersing the fish to all waterways (Figures 3 and 4) that could impact on Army facilities (not just the hospitals). There was some opposition to this in Australia. Frank Marshall, ichthyologist and curator at the Queensland Museum, argued against the release of exotic species in Australian waters. He particularly fought against the use of *Gambusia* (and *Poecilia*) for controlling mosquitoes in Queensland (Haysom 2000).

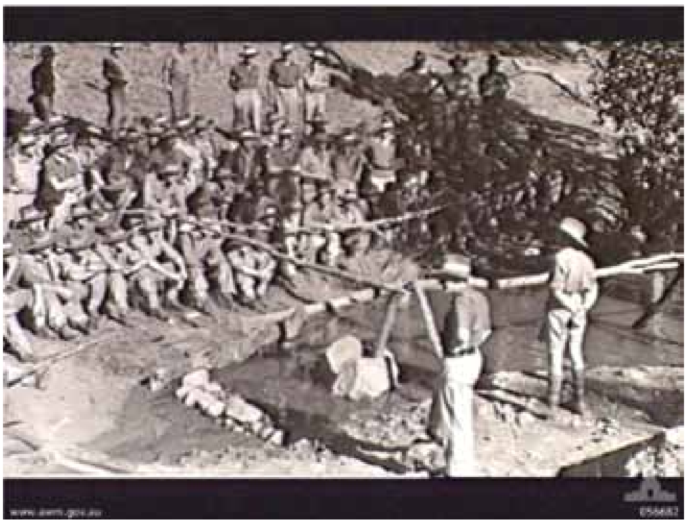

Figure 3. Herberton area, Queensland, 16/08/1943. Corporal G. D. Roberts of the 9th Australian Anti-malaria Control Unit, demonstrating control of mosquito larvae by the introduction of *Gambusia holbrooki* into rivers and streams. Source: Australian War Museum.

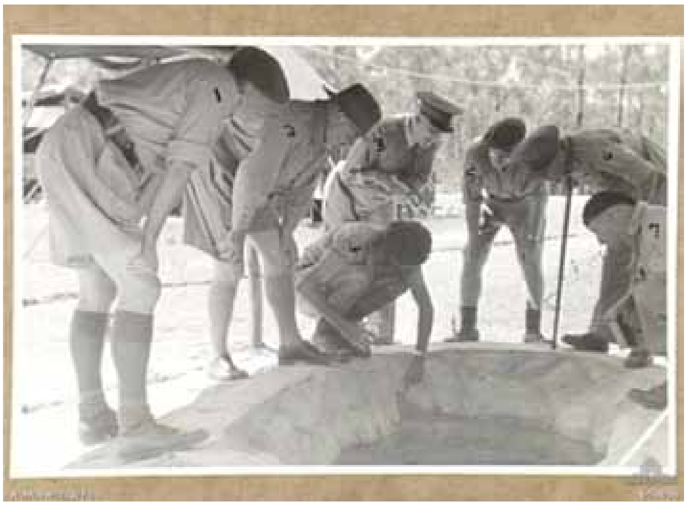

Figure 4. Southport, Queensland, 13/01/1944. The Australian army representative in London, Lieutenant-General E. K. Smart, DSO, MC, (2) inspecting gambusia fish in a breeding pool at the 4th Armoured Brigade hygiene school. These fish would later be released in creeks and waterholes to destroy the malarial mosquito larvae. Source: Australian War Museum.

From 1942 to 1946, gambusia were bred and released extensively in Australian waterways, especially in the Greater Brisbane area, Cairns and Atherton region, Northern Territory, New South Wales and Victoria. In some locations, still water bodies were drained, and kerosene and diesel were used to layer the surface water in an attempt to kill mosquito wrigglers (Spencer 1992).

The sudden surge in the distribution and abundance of gambusia during the war years expedited the realisation of gambusia's ecological damage. Gambusia was now widespread across Australia and present in all the mainland states and territories; it was present in most locations that were available for its colonisation (Rowe *et al.* 2008; Figure 5). After WW II, the need to continue to breed and disperse gambusia lessened as synthetic insecticides became readily available. The spread of gambusia slowed considerably in Australia; for example, gambusia did not reach Tasmania until 2004 (Keane and Neira 2004).

Gambusia becomes an ecological disaster

Although gambusia was highly prized for its supposed ability to consume large numbers of mosquito wrigglers, its ability to consume other freshwater organisms quickly altered its status in Australia (and many other countries) from that of a saviour and boon to humanity to that of an unwanted pest species (McKew 1999). Immediate impacts include its depredation of fish and frog eggs and larvae and direct predation or attack and injury or death to adult fish, frogs and aquatic invertebrates (Pyke and White 2000; Pyke 2006; Reynolds 2009).

Gambusia can adversely impact native fauna in several ways, including by competition for food and resources and through direct predation. Milton and Arthington (1982) and Courtenay and Meffe (1989) reported the role of gambusia in the decline of various species of native fish. In Australia, gambusia has been nominated as an imminent threat to Red-finned Blue Eye (*Scaturiginichthys*

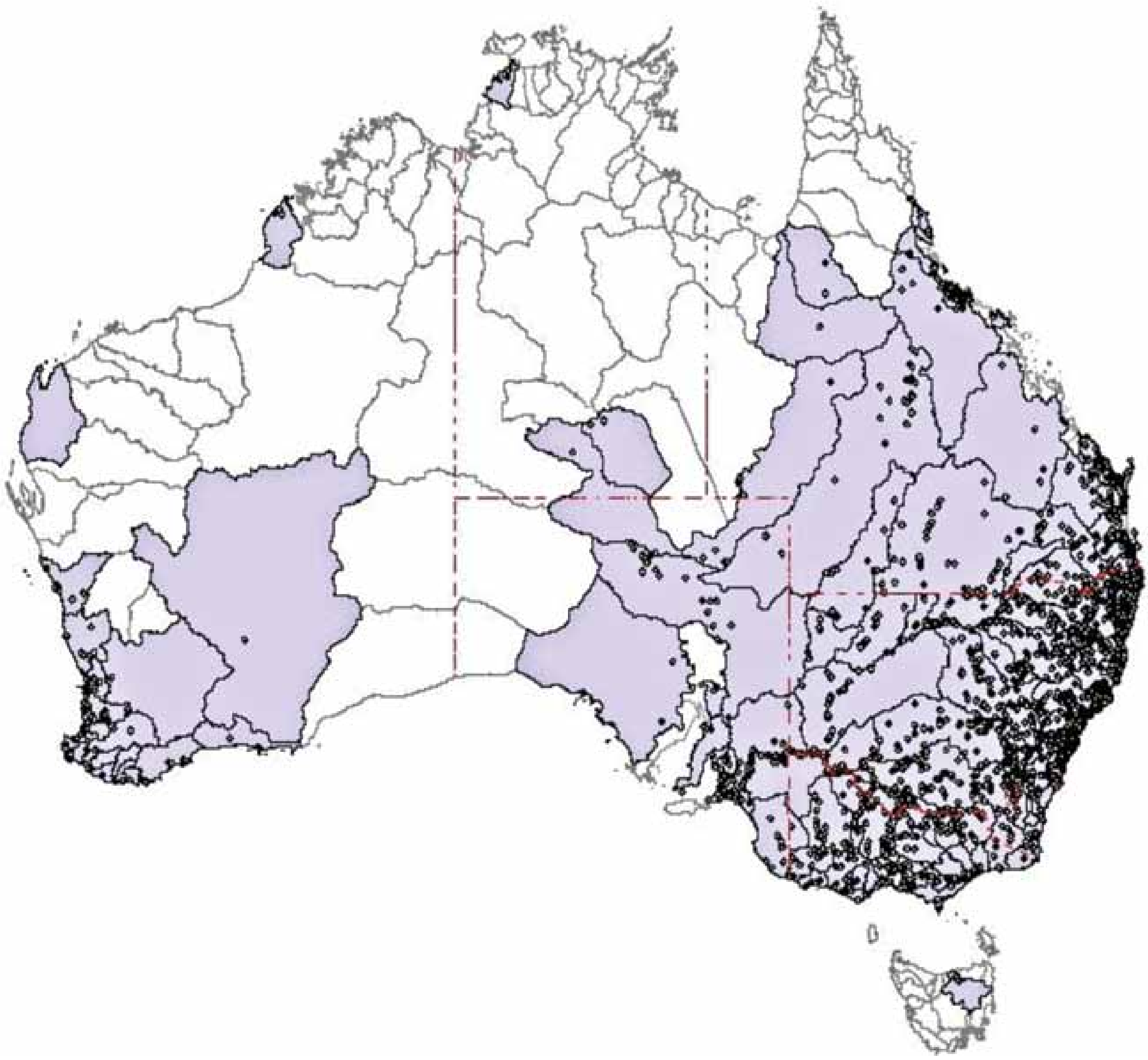

Figure 5. Distribution of *Gambusia holbrooki* in Australia (after Gehrke and Harris 2000). Coloured areas indicate affected drainages.

vermeilipinnis, Pseudomugilidae) and the Edgbaston Goby (*Chlamydogobius squamigenus*, Gobiidae) (Unmack and Brumley 1991; Unmack 1992; Wager 1994, 1995). They also negatively affect Southern Blue Eye (*Pseudomugil signifer*) populations (Howe *et al.* 1997) and tadpoles (Morgan and Buttemer 1997; Webb and Joss 1997). Glover (1989) reported that gambusia were responsible for declines in the Desert Goby (*Chlamydogobius eremius*) and Spangled Perch (*Leiopotherapon unicolor*, Terapontidae) populations inhabiting Clayton Bore in South Australia. Speculation that gambusia preyed on the eggs and larvae of rainbowfish (Melanotaeniidae) in the wild (Arthington and Lloyd 1989; Arthington 1991) was subsequently verified (Ivantsoff and Aarn 1999). In New Zealand, Barrier and Hicks (1994) showed that although gambusia was harassed by the larger Black Mudfish (*Neochanna diversus*, Galaxiidae), gambusia ate their larvae (Table 3).

Gambusia has harmed native fish populations in other ways. By consuming algae-eating zooplankton, these fish increase the chances of algae blooms, thus reducing water quality. They are very aggressive, and tend to attack other fish and nip their fins, leading to infection or death (Rowe *et al.* 2008). Populations of the Purple-spotted Gudgeon have declined as a result of high densities of gambusia (McDowall 1990). It has been suggested that gambusia may seriously impact native Tasmanian galaxiids (Keane and Neira 2004) as they are known to attack and kill adult *Galaxias gracilis* in New Zealand. Where gambusia become locally common and abundant they may reduce or exterminate native fish populations, altering aquatic ecosystems. Decreasing the number of native fish species in a waterbody may reduce the predation rate on mosquitoes. Because of their high reproductive rate (an average of 50 young per brood, with up to nine broods per year), fast maturation (sexual maturity is reached in two months), and aggressive behavior, gambusia can overwhelm most native fish (Pyke 2005).

Gambusia also pose a threat to populations of native frogs (Table 4). They prey upon the tadpoles of the Ornate Burrowing Frog *Opisthodon ornatus* (Keane *et al.* 2004) and are also known predators of tadpoles of other closely-related frog species such as the Green and Golden Bell Frog *Litoria aurea* and the Bleating Tree Frog *L. dentata* (Morgan and Buttemer 1996; Pyke and White 2000). The Southern Bell Frog *Litoria raniformis* in Tasmania is believed to be directly threatened by gambusia, and the frog is listed on Tasmania's Threatened Species Protection Act of 1995 (Keane and Neira 2004). Observations of tadpoles of the Southern Bell Frog suggest that they are naïve to gambusia as they make little effort to avoid these fish when present. In addition, gambusia and other introduced fish may reduce the suitability of permanent water bodies as breeding sites for pond-breeding amphibians such as the Green and Golden Bell Frog (Hamer *et al.* 2002).

Gambusia may also have a negative influence on some frog species' choice of breeding habitat. G. holbrooki has been shown to prey on the eggs and tadpoles of several threatened frog species (McKay 1984; Pyke 2008). The species is purported to also impact on macro-invertebrates such as rotifers, mayflies, beetles, dragonflies and molluscs (Pressey and Harris 1988).

Many ichthyologists believe that native species are more effective in population control than gambusia. These include species such as the Western Minnow and pygmy perches (Pollard *et al.* 1980). Unfortunately, gambusia may have exacerbated the mosquito problem in many areas by eating or outcompeting native invertebrate predators of mosquito larvae. Because of their aggressive nature and high fecundity, gambusia can overtake most native species in an area, drastically harming local native populations. Even if they were needed for mosquito control, studies have shown that at least 5,000 fish/ha would be needed for effective control. However, the breeding environments

Table 3: Native fish species in Australasia impacted by Gambusia

Species	Mode of Impact	Reference
Red-finned Blue Eye *Scaturiginichthys vermeilipinnis*	Competition	Unmack and Brumley 1991; Wager 1994, 1995
Edgbaston Goby *Chlamydogobius squamigenus*	Competition	Unmack 1992; Wager 1995
Desert Goby *Chlamydogobius eremius*	Competition	Glover 1989
Spangled Perch *Leiopotherapon unicolor*	Competition	Glover 1989
Southern Blue Eye *Pseudomugil signifer*	Competition	Howe *et al.* 1997; Knight 1999
Rainbowfish (Melanotaeniidae)	Predation	Arthington and Lloyd 1989; Arthington 1991
Black Mudfish *Neochanna diversus*	Predation	Barrier and Hicks 1994
Purple-spotted Gudgeon *Mogurnda adspersa*	Predation	McDowell 1990
Native Galaxia *Galaxias gracilis*	Predation	Keane and Neira 2004
Southern Pygmy Perch *Nannoperca australis*	Aggression (biting); competition (when food is limited)	Koster 1997
Oxylean Pygmy Perch *Nannoperca oxleyana*	Aggression; competition	NPWS 2003
Murray Hardyhead *Craterocephalus fluviatilis*	Competition	NPWS 2003
Silver Perch *Bidyanus bidyanus*	Competition	NPWS 2003
Olive Perchlet *Ambassis agassizii*	Competition	NPWS 2003

Table 4: Australian frog species impacted by *Gambusia holbrooki*

Species	Mode of Impact	Reference
Ornate Burrowing Frog *Opisthodon ornatus*	Predation of tadpoles	Keane and Neira 2004
Spotted Grass Frog *Limnodynastes tasmaniensis*	Predation of hatchling tadpoles	Harris 1995, Healey 1998
Brown Striped Marsh Frog *Limnodynastes peronii*	Predation of hatchling tadpoles	Webb and Joss 1997
Moaning Frog *Heleioporus eyrei*	Predation of tadpoles	Reynolds 2009
Glauert's Froglet *Crinia glauerti*	Predation of tadpoles	Reynolds 2009
Sign-bearing Froglet *Crinia insignifera*	Predation of tadpoles	Reynolds 2009
Tschudi's Froglet *Crinia georgiana*	Predation of tadpoles	Reynolds 2009
Slender Tree Frog *Litoria adelaidensis*	Predation of tadpoles	Reynolds 2009
Green and Golden Bell Frog *Litoria aurea*	Predation of tadpoles	Pyke and White 2000
Brown Tree Frog *Litoria ewingi*	Predation	McGilp 1994
Bleating Tree Frog *Litoria dentata*	Predation of tadpoles	Morgan and Buttemer 1997
Southern Bell Frog *Litoria raniformis*	Predation of tadpoles	Keane and Neira 2004

of mosquitoes are often ephemeral and standing water is unreliable, so fish predators may have little effect from year to year on mosquito populations (Kitching 1986).

The future

Since 1982 the World Health Organisation has no longer recommended the use of gambusia for malaria control purposes and has indicated that it should not be introduced into new areas. In Australia, *Gambusia holbrooki* was listed in 1999 as a Key Threatening Process under the New South Wales *Threatened Species Conservation Act* 1995 (NPWS 2003), making it illegal for landowners to further spread the fish (McKew 1999), although the species is already widespread (Figure 5).

The release of gambusia into the wild is one of the biggest problems affecting local rivers throughout eastern Australia. Proposals for gambusia population control have included introducing viral, bacterial, or fungal diseases and parasites into overpopulated areas. However, many diseases can jump species and could infect native fish (Gambusia Control Network 2010). The Tasmanian government has taken steps to eradicate gambusia by containing current populations and minimizing paths of dispersal (Keane and Neira 2004). The extermination of gambusia from pond sites is not simple or hazard-free: partially drained or emptied pond sites can be treated with lime, raising the pH of the water and mud, killing the remaining fish (Komak and Crossland 2000). Fish poisons (such as Rotenone) are effective only in highly confined situations (Pyke 2008). In many locations, these methods cannot be effectively employed.

Courtenay and Meffe (1989) and Pyke (2008) reviewed the role of gambusia in mosquito control and found the fish to be relatively ineffective. In addition, they concluded that gambusia is too aggressive and predatory to warrant indiscriminate introduction, and supported a ban on its use as a control agent. In view of the ecological damage caused by gambusia, Laha (2006) advocated widespread control of gambusia in introduced sites through habitat modification. In Australia, gambusia are unlikely to be controlled in the wild in the immediate future unless a target-specific control mechanism is found.

The scale of the ecological disaster created by the introduction of *Gambusia holbrooki* into Australia still has not been adequately assessed. Impacts on a few aquatic vertebrate species have been recorded, but the wider impacts on invertebrates and aquatic ecosystems remain a mystery. It is likely that as human-mediated environmental degradation continues, exotic species such as gambusia will continue to be assisted in their spread into wider and more remote environments. The history of *Gambusia holbrooki* in Australia demonstrates how easy it is to introduce species and not anticipate the environmental consequences of that action. It also attests to the difficulty in eradicating exotic species once they have been established. It is hoped that gambusia may serve as a salient example to all and sundry of the folly of introducing any species without rigorous testing of the potential environmental impacts.

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