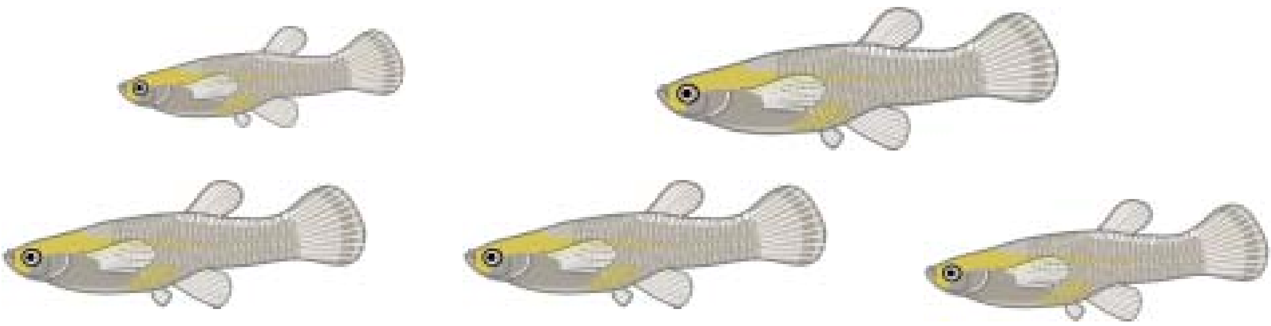
*Approved* NSW Threat Abatement Plan

# Predation by *Gambusia holbrooki*

# - The Plague Minnow



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## Executive Summary

This document constitutes the NSW National Parks and Wildlife Service (NPWS), threat abatement plan for the listed key threatening process Predation by *Gambusia holbrooki* – the Plague Minnow, and as such considers the known impacts and management actions necessary to abate this threat on native fauna, in particular threatened frogs.

Predation by *Gambusia holbrooki*, hereafter referred to as gambusia, was listed in January 1999 as a key threatening process on Schedule 3 of the NSW *Threatened Species Conservation Act 1995* (TSC Act). The NSW Scientific Committee determined that predation by gambusia is a serious threat to the survival of threatened species such as the green and golden bell frog (*Litoria aurea*) and New England bell frog (*Litoria castanea*) and could cause other native frog species to become threatened. The NPWS is required to prepare a Threat Abatement Plan (TAP) to manage this key threatening process, so as to abate, ameliorate or eliminate the adverse impacts of gambusia predation.

Since their introduction into Australia in 1925 for the purpose of mosquito control, gambusia have become widespread in NSW, especially modified waterways, and are considered to be a contributing factor to the decline of frogs (threatened or otherwise) as well as other native species such as freshwater fishes and macro-invertebrates.

This threat abatement plan provides a strategy for the management of gambusia in NSW. Given the widespread distribution of gambusia and the difficulties posed by removing the species from the environment, this plan identifies those frog species considered most at risk from predation by gambusia in order to make the most effective use of management resources.

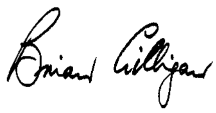
The plan seeks to minimise ongoing human dispersal of gambusia through a program of education and awareness of the risks associated with introducing the species into the environment, particularly habitats of key threatened frog species.

In addition, the plan seeks to reduce the impacts of gambusia at sites where control is most critical. The plan proposes to achieve this by undertaking a program of gambusia control at key habitats for high priority threatened frog species. At sites where gambusia removal is not considered feasible, opportunities for the creation of gambusia-free supplementary habitat will be evaluated. Sites will be monitored on an ongoing basis to assess the effectiveness of the gambusia control program.

A number of research actions are recommended in order to clarify aspects of the ecology of gambusia and its impacts on frog species. Additional information is also required on the efficacy of proposed control methods and their impact on non-target species. Outcomes from this research will assist in the future management of gambusia.

Although this threat abatement plan targets the impact of gambusia on threatened frogs. It also documents the potential effects of this on non-threatened frog species, freshwater fishes and other aquatic organisms such as macro-invertebrates. The plan recognises that effective long-term control of gambusia across the landscape will only be achieved in partnership with programs that endeavour to restore aquatic ecosystems. This plan therefore links with other broad-scale water reform processes that seek to address aspects of habitat modification favoured by gambusia.

The NPWS will coordinate the implementation of this plan over a five-year period.



**Brian Gilligan**
**Director-General**

**Bob Debus**
**Minister for the Environment**

## Acknowledgements

This threat abatement plan has been prepared by Ron Haering (NPWS). Background material (sections 1 to 8 of this plan) has been sourced from a review of the literature prepared by the Arthur Rylah Institute for Environmental Research under contract to the NPWS (McKay *et al.* 2001).

Ross Wellington, Nick Sheppard, (both NPWS) John Pursey, David Pollard and Jamie Knight (NSW Fisheries), Roger Dekeyzer (Environment Protection Authority), Michael Mahony (University of Newcastle) and Tony Miskiewiez (Wollongong City Council) assisted with the preparation of this plan. Thanks to Angela Arthington (Griffith University), Jack Baker, Andrew Leys, Rodney James, Melanie Bannerman, Paul Downey, Paul Mahon, and Joanne Edney (all NPWS) and Marion Anstis for their comment and/or editorial input.

Special thanks are due to Michael Mahony and Marion Anstis whose expertise enabled the preparation of Appendix 3.

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**Introduction**

Gambusia has been colloquially described as the 'animal weed' of our aquatic environment, because of its ability to rapidly reproduce, disperse widely and occupy diverse habitats, to the detriment of native species. This small, introduced fish is also highly aggressive and predatory.

Originally introduced in 1925 from the USA into the Royal Botanic Gardens Sydney, for the purpose of mosquito control. Gambusia are now common and widespread, occurring in most freshwater habitats in south-eastern Australia, as well as the coastal drainages of Queensland, and some parts of the Northern Territory and Western Australia. It has been an extremely successful invader assisted by human dispersal and facilitated by its high reproductive potential, fast maturation rate, flexible behaviour and broad environmental tolerances. In five months, a population of gambusia can increase to over 100,000 fish after natural mortalities.

The effectiveness of gambusia to control mosquitoes has generally failed internationally and the World Health Organisation no longer recommends its use for malaria control programs primarily due to its harmful impact on native fish. What remains however, is the legacy of another introduced species establishing itself in Australia and impacting on native species including frogs, fish and macro-invertebrates. Predation by gambusia is now listed as a key threatening process in NSW.

There are presently no effective and specific methods to control gambusia. Once introduced, it is almost impossible to eradicate from the environment, particularly from connected waterways such as creeks, rivers and streams, and large permanent water bodies. A number of physical, chemical and biological approaches have been trialled with varying degrees of success and inherent risks. An integrated targeted strategy is proposed in this plan, which combines public education, gambusia control (where feasible) and ecological rehabilitation. Actions identified in the plan are targeted predominantly towards ameliorating the impacts of gambusia on frogs, particularly threatened frog species.

# 1. Legislative Framework

## 2.1 Commonwealth Legislation

### Wildlife Protection (Regulation of Exports and Imports) Act 1982

Regulations concerning the import of exotic species and export of native species are provided under the *Wildlife Protection (Regulation of Exports and Imports) Act 1982*. Schedule 6 of the Act includes a list of fish, which can be imported into Australia. Gambusia are not included on this list. Persons wishing to import gambusia would need to have the species approved for inclusion on this Schedule.

Given the widespread availability of the species in Australian waterways and its lack of value as an ornamental fish (see section 3), it is unlikely that gambusia would knowingly be imported into Australia.

### Environment Protection and Biodiversity Conservation Act 1999

The impacts of gambusia are not listed as a key threatening process under this Act.

## 2.2 NSW Legislation

**Threatened Species Conservation Act 1995**

The NSW *Threatened Species Conservation Act 1995* (TSC Act) aims to conserve biological diversity, prevent extinction and promote the recovery of listed species, populations and ecological communities. The ultimate goal of the TSC Act is to recover threatened species, populations and ecological communities, so that their long-term survival in nature can be assured. This involves eliminating or managing processes that threaten the survival or evolutionary development of such species. The key mechanisms provided in the TSC Act to achieve this goal are the preparation and implementation of recovery plans and threat abatement plans.

The TSC Act provides for the listing of key threatening processes. A threatening process is eligible to be listed if, in the opinion of the Scientific Committee it:

a) adversely affects two or more threatened species, populations or ecological communities, or
b) could cause species, populations or ecological communities that are not threatened to become threatened

Predation by *Gambusia holbrooki* the Plague Minnow was gazetted as a key threatening process under the TSC Act in January 1999. The final determination of the NSW Scientific Committee is provided in Appendix 1. The rationale for this determination is based on the view that predation by gambusia is a serious threat to the survival of threatened species such as the green and golden bell frog (*L. aurea*) and New England bell frog (*L. castanea*) and other native frog species. The NPWS is therefore required to prepare a TAP to manage this key threatening process, so as to abate, ameliorate or eliminate the adverse impacts of gambusia predation on threatened species.

This plan constitutes the final approved TAP for this listed key threatening process. The TSC Act requires Ministers and public authorities to take any appropriate action available to them to implement the measures included in the plan for which they are responsible. Furthermore, they must not make decisions that are inconsistent with the provisions of the plan. A public authority identified in a plan as responsible for the implementation of particular measures must report to Parliament on actions taken to implement those measures. The NPWS has been identified as the implementation authority for this TAP.

The TSC Act requires the final approved recovery plan to include a summary of advice given in the NSW Scientific Committee submission to the draft plan and a reason for any departure from that advice. In regard to this plan, the NSW Scientific Committee commented that overall, the plan is logical and well focused. The Scientific Committee also noted that the frog ranking system provided in Appendix 3, should be periodically updated as ongoing research clarifies the uncertainty about which native frog species are most at risk from predation by gambusia.

**Fisheries Management Act 1994**

The *Fisheries Management Act 1994* (FM Act) aims to conserve, develop and share the fishery resources of NSW for the benefit of present and future generations. The objectives of this Act relate to conserving fish stocks and protecting key habitats, conserving threatened species, populations and communities, promoting ecologically sustainable development, promoting viable commercial fishing and aquaculture industries, promoting quality recreational fishing opportunities and sharing fisheries resources between users.

NSW Fisheries are responsible for the management of fish resources in NSW and has management responsibility for all aquatic animals (with the exception of aquatic mammals, birds, reptiles and amphibians which are managed by NSW NPWS) including fish and their habitat in all waters of the State (including private and public waters and all permanent and intermittent waters). Through amendments to the FM Act, NSW Fisheries are responsible for threatened fish species, populations and ecological communities and for the conservation of biodiversity of all fish and marine vegetation.

Like the TSC Act, the FM Act includes provision for the listing of threatened species, populations and ecological communities and key threatening processes and includes provisions for the preparation of recovery plans and threat abatement plans. The NSW Fisheries Scientific Committee has made a final recommendation to list the "Introduction of fish to fresh waters within a river catchment outside their natural range" as a key threatening process. This listing cites the impacts of gambusia as part of this threatening process.

**Noxious fish and noxious marine vegetation**

The FM Act, Part 7, Division 6 (Sections 209 to 213) provides for the declaration of different categories of noxious fish (which represent the different levels of threat they pose to the aquatic environment) and includes penalties for their sale and possession. It is a defence against prosecution under Section 211 if a person neither introduced nor maintained a noxious fish in those waters. Conditions may be included in aquaculture permits for the destruction or control of noxious fish. Section 213 enables the destruction of noxious fish.

*Gambusia* is not currently declared a noxious fish in NSW.

Clarke *et al.* (2000) reviewed the status of gambusia in other Australian states. It is classified as a pest in Queensland under the *Fisheries Act 1994,* where the species may not be released into waters or held in captivity. In Western Australia gambusia must not be returned to the water. In Victoria, it is listed as a noxious species under the *Fisheries Act 1995*.

**Release or importation of fish**

Part 7, Division 7 (Section 216) of the FM Act prohibits the release of any live fish (except under a permit) into any waters. Section 217 prohibits any person bringing live fish into NSW not taken from NSW waters except under permit. A person who sells or buys or has possession of a fish knowing it has been brought into the State is guilty of an offence.

This section of the FM Act applies only to the release of fish into the sea, river, creek or other naturally flowing stream or water or into a lake. This excludes other waterbodies such as farm dams, outdoor ponds or other forms of aquaria.

**NSW Fisheries – Introduction and Translocation Policy**

This policy provides background on the introduction of native and non-native fish species, translocations, aquaculture, impact of introductions/translocations and legislation. The policy states:

> 7.1 All stockings of fish into NSW waters require a permit from NSW Fisheries.
>
> 7.2 NSW Fisheries will not permit any further introductions or translocations of native or non-native species into NSW waters, except as permitted elsewhere in this policy.

NSW Fisheries distinguishes between exotic, alien, introduced and translocated species. Gambusia are classified as alien, ie a species which was brought into Australia from a foreign country and has established wild populations. This policy notes that species such as gambusia have been introduced into the State either accidentally or deliberately.

**Environmental Planning and Assessment Act 1979**

Land use within NSW is primarily regulated by the *Environmental Planning and Assessment Act 1979* (EP&A Act). The EP&A Act seeks to encourage, *inter alia*, ecologically sustainable development by managing the development process and the effects of development on the environment.

When evaluating a proposed development or activity, consideration by a consent or determining authority should be given to the potential of that proposed development or activity, resulting in the introduction of gambusia into the natural environment, including its effects on threatened species (Section 79C and Section 111 of the EP&A Act).

In addition, Section 5A of the EP&A Act sets out eight factors to be considered when deciding whether there is likely to be a significant effect on threatened species, populations and ecological communities and hence, if a Species Impact Statement (SIS) is required. Part (g) of this ‘eight part test’ includes the following factor for consideration - whether the development or activity proposed is of a class of development or activity that is recognised as a threatening process. This part would be relevant if, for example, a proposed development was likely to result in the introduction of gambusia into an area.

It is a requirement of the NPWS that all proposed activities (including pest control) on NPWS land are assessed under Part 5 of the EP&A Act. This involves an examination of whether the activity is likely to significantly affect the environment, including threatened species, populations and ecological communities and their habitats. The mechanism to undertake this assessment is generally regarded as a Review of Environmental Factors. Where a significant effect is likely, the EP&A Act requires the preparation of an environmental impact statement, and in the case of a significant effect on threatened species, populations or ecological communities, a SIS.

**Pesticides Act 1999**

The *Pesticides Act* regulates and controls the use of pesticides within NSW. Under the Act, it is illegal to possess, prepare for use, or use a pesticide in NSW unless it is registered by the National Registration Authority for agricultural and veterinary chemicals (NRA) or covered by an NRA permit issued under the Commonwealth *Agricultural and Veterinary Chemical Code Act 1994*. The *Pesticides Act* requires strict adherence to label instructions, as set out by the NRA, when using a registered pesticide.

The Pesticides Act also makes it an offence to use a pesticide in a way that harms any non-target animal or plant. A defence against prosecution is provided where a person takes all reasonable precautions and exercises all due diligence when using the pesticide and the offence was due to causes beyond the person's control.

Rotenone for example, is a registered pesticide commonly used in various formulations such as 'Derris Dust' for agricultural pest control purposes. Rotenone is also an effective broad- spectrum piscicide that is toxic to most fish and has been used to kill pest fish species such as carp and gambusia (Hall 1988; Sanger and Koehn 1997; Koehn *et al* 2000; Willis and Ling 2000). Its application has generally been limited to small closed water bodies such as ponds or farm dams.

Rotenone is not currently registered as a piscicide in Australia. The application of Rotenone to remove gambusia would therefore require its registration as a piscicide with the NRA and approval for its use from the NSW Environment Protection Authority and NSW Fisheries. Before registering any product, the NRA is required to conduct a rigorous assessment of its potential impacts on the environment, human health and trade and of its likely effectiveness for its proposed uses. Alternatively, the NRA can consider issuing either an 'off-label' permit for unregistered/registered products for minor or emergency uses, or a trial permit for research purposes to determine its efficacy data and assess non target impacts.

**Water Management Act 2000**

The *Water Management Act 2000* (WM Act) is the principal piece of legislation controlling water management across NSW and is administered by the NSW Department of Land and Water Conservation (DLWC). The WM Act provides for the development of water sharing plans and water management plans by community based Water Management Committees (which includes NPWS representation). The WM Act may allocate the volume of water to be used for various purposes, including irrigation and environmental flows, identify the timing of water extraction for various purposes and discuss the natural flow regimes of a catchment or subcatchment.

Water plans must be consistent with government advice and policy, including the Interim State Water Management Operating Plan, which sets the overarching policy context, targets and strategic outcomes for the States's water resources.

**Catchment Management Amendment Bill 2001 (not yet passed) and the Catchment Management Act 1989**

The amendments to the *Catchment Management Act 1989* (CM Act) will provide that certain plans prepared under the WM Act must be consistent with any relevant catchment management plan. The Catchment Management Plans (also called "blueprints") are expected to drive regional investment priorities under the National Action Plan for Salinity and Water Quality and the Natural Heritage Trust Mark 2. The establishment of Catchment Management Boards on which NPWS is represented will drive the development of these catchment management plans.

**NSW Weirs Policy (1995)**

The NSW Weirs Policy is a component of the State Rivers and Estuaries Policy (1991) being implemented by DLWC. The goal of the State Weirs Policy is to halt and where possible reduce and remediate the environmental impacts of weirs. The review of weirs will assist with the development of operational and structural changes needed to achieve river flow and water quality objectives.

**NSW Wetlands Management Policy (1996)**
The NSW Wetlands Management Policy adopts nine principles that aim to minimise any further loss or degradation of wetlands and, where possible, restore degraded wetlands. Principle six states that "Natural wetlands should not be destroyed, but when social or economic imperatives require it, the rehabilitation or construction of a wetland should be required". This policy is consistent with the objectives of the WM Act. This policy is also being implemented by DLWC.

# 3. Industry Framework

Gambusia are unlikely to play an important role in the aquarium industry and due, to its ubiquitous distribution is unlikely to be imported specifically as an ornamental fish for the aquarium trade. In NSW, aquarium retail outlets are currently permitted to trade in gambusia supplied from local sources. It is principally traded as a fish to be fed to other aquarium fish, being readily available from local sources (Jared Patrick pers. comm.). The number of gambusia traded in this manner is difficult to estimate. As they are sourced locally and are relatively inexpensive, it is unlikely that any significant numbers are sold.

# 4. Description

## 4.1 Taxonomy and Morphology

***Gambusia holbrooki*** (Girard 1859)

Order: Cyprinodontiformes
Family: Poeciliidae
Common name: Eastern Gambusia, Mosquito Fish, Plague Minnow

The history of introduction(s) and subsequent spread of gambusia are poorly documented and confusion exists regarding which subspecies is actually present in Australia (Lloyd and Tomasov 1985). There is confusion about the correct species name in Australia (Howe 1995). The following summary of taxonomy should clarify this.

There are approximately 30 species within the genus gambusia most of which are rare and restricted in range (Rivas 1963; Rosen and Bailey 1963). Prior to studies by Lloyd and Tomasov (1985), authors named the Australian introduction as *Gambusia affinis*, which is originally distributed from across south-eastern USA to Texas (Lloyd and Tomasov 1985). Two subspecies of *G. affinis* were subsequently identified in south-eastern USA: the eastern form *G. affinis holbrooki* (Krumholz 1948) and the western form, *G. affinis affinis* (Baird and Girard 1853). Lloyd and Tomasov (1985) confirmed Wilson's (1960) interpretation that the subspecies *G. a. holbrooki* is the taxon introduced into Australia. Wooten *et al.* (1988) later reinstated the original species *G. holbrooki* (Girard 1859) and *G. affinis* (Baird and Girard 1853) into two species. The species found in Australia is presently named *G. holbrooki* (Lloyd and Tomasov 1985; Arthington *et al*. 1999).

In about 1905, "mosquitofish" was adopted as the common name for gambusia (Lloyd 1990a), replacing the previous (American) name "topminnow" (Krumholz 1948; Lloyd 1990). The name mosquitofish implied that gambusia was as an effective mosquito control agent, making it the "logical" choice for the solution to mosquito control problems without first considering the use of native fish as potential control agents (Lloyd 1990a). Gambusia is now commonly referred to as the plague minnow, in light of its proliferation in Australian waters.

The following description of the morphology of gambusia is adapted from McDowall (1996) and Cadwallader and Backhouse (1983):

***Body:*** A tiny, stout fish with a deep rounded belly and a flattened upper surface, especially the head
***Eyes:*** large, positioned near dorsal profile
***Mouth:*** small, upturned and protrusible, lower jaw a little longer than upper. Bands of minute teeth on both jaws
***Scales:*** head and body covered with large cycloid scales (28-32, usually 30-31 laterally)
***Dorsal fin:*** single, soft rayed (6-8 rays, usually 7), short based, high, rounded, and situated posteriorly
***Anal fin:*** (9-11 rays, usually 10) rounded or elongate, pointed
***Pectoral fins:*** short, rounded, positioned high on sides near top of gill openings
***Pelvic fins:*** abdominal, tiny rounded; bases close together. Caudal fin large, rounded
***Lateral Line:*** no lateral line
***Vertebrae:*** 31-33
***Gill rakers:*** 13-15 stout gill rakers of moderate length

Gambusia is sexually dimorphic, with females much larger bodied than males (maximum standard lengths of 35 mm and 60 mm respectively) (McDowall 1996; Cadwallader and Backhouse 1983). Males cease growing when they reach maturity, but females continue to grow until they die (Cadwallader and Backhouse 1983; Vargas and de Sostoa 1996).

Gambusia are generally green olive to brown on the back, the sides are grey with a bluish sheen, and the belly is silvery-white (Cadwallader and Backhouse 1983; McDowall 1996). The lower jaw is steel blue and often has a dark, diagonal stripe below the eye. Fins are colourless, except for the dorsal and caudal fins, which may bear numerous fine black spots, sometimes forming indistinct rows. Individuals of some populations of gambusia have brownish-black spots on the sides (Cadwallader and Backhouse 1983).

Females have a distinct black blotch surrounded by a golden patch just above the vent. Males have a highly modified anal fin, the third, fourth and fifth rays of which are elongated and thickened with very small hooks at the tip. These form the gonopodium or intromittent organ, used to facilitate internal fertilisation of eggs in the female (Cadwallader and Backhouse 1983; McDowall 1996).

## 4.2 Distinguishing Characteristics

There are no other species of gambusia present in NSW. However, there are several native and introduced species, which may potentially be confused with gambusia (Table 1).

**Table 1. Fish species occurring in NSW, which could potentially be confused with gambusia**

| Common name and scientific name | Distinguishing features | Distribution | Habitat conditions |
|---|---|---|---|
| Darling River Hardyhead<br>*Craterocephalus amniculus*<br>(Small individuals can be confused with *gambusia*) | Protrusible mouth and thin lips. Scales almost circular and barely overlapping. | Upper tributaries of Darling River | Gently flowing, shallow, clear water or in aquatic vegetation at the edges of such waters. |
| Murray Hardyhead<br>*Craterocephalus fluviatilis*<br>(Small individuals can be confused with *gambusia*) | Mouth restricted by a labial ligament from 1/3 too halfway along the thin lips. Scales on top of head robust and large, with a single large interorbital scale reaching as far as the anterior margin. | Once abundant in southern waters of inland NSW. No records in the past 10 years | A highly mobile schooling fish that often found over very sandy shallow flats. |
| Marjorie's Hardyhead<br>*Craterocephalus marjoriae*<br>(Small individuals can be confused with *gambusia*) | Head usually blunt, slightly flattened and sloping towards snout. Mouth protrusible, with small, sharp, inwardly pointing teeth | Clarence River in north-eastern NSW | Often found in large schools in shallow water with a gravelly or sandy bottom though also frequents weedy sections of streams. |
| Flyspecked Hardyhead<br>*Craterocephalus stercusmuscarum fulvus*<br>(Small individuals can be confused with *gambusia*) | Small fish, more slender than most hardyheads; head in larger specimens tending to slope downwards toward snout. Lips moderately thick; a small protrusible mouth. | Previously present in most parts of the Murray-Darling drainage system in NSW | Usually schools in still or gently flowing water over sand, gravel or mud. |
| Pacific blue-eye<br>*Pseudomugil signifer*<br>(Small individuals can be confused with *gambusia*) | Small fish, semi-transparent body which can vary in colour from pale olive, yellow and blueish. The iris of the pacific blue eye is blue. There is often a line of pearly spots along the side of the body. Males can grow to 88 mm, females to 63 mm in length. | East coast of Australia, from Cooktown in Queensland to Narooma in NSW. | Prefers clear fast flowing streams and mangrove regions of estuaries. |
| Guppy<br>*Poecilia reticulata**<br>(Small individuals can be confused with *gambusia*) | Single dorsal fin a little behind middle of body. Males brightly coloured with irregular markings of green, turquoise, blue, red, orange and yellow. | Occurring in coastal drainages of northern NSW | Still or gently flowing waters. Around margins and edges of aquatic vegetation. Prefers water above 15°C. |
| Swordtail<br>*Xiphophorus helleri**<br>(Small individuals can be confused with *gambusia*) | Modest size, dorsal fin high on arching back. Tail truncated, lower margin elongated to form a long sword in male. Aquarium fish are bright orange on body and fins; wild populations olive brown with orange-red midlateral stripe. | Occurring in coastal drainages of northern NSW | Gently flowing streams with sparse vegetation over gravelly substrates. |
| Platy<br>*Xiphophorus maculatus**<br>(Small females may be confused with female *gambusia*) | Very deep bodied and much compressed, with dorsal fin high on arching back. | Occurring in coastal drainages of northern NSW | Prefers still warm water above 20°C. |

(Ivantsoff and Crowley 1996; Arthington and McKenzie 1997; Allen 1989; McDowall 1996; Australian Museum 2002). * Introduced species.

# 5. History of Introduction

## 5.1 Species Origin and Entry into Australia

Gambusia are native to southern USA and Northern Mexico (Lloyd and Tomasov 1985; Clarke *et al.* 2000). The native range of gambusia is the area from central Alabama, east into Florida and throughout the Atlantic coastal drainages northwards to New Jersey (Rivas 1963; Wooten *et al.* 1988).

Gambusia was introduced into Australia in 1925 from Georgia (USA) (Wilson 1960; Myers 1965; Bayly and Williams 1973; McKay 1984), to control mosquitoes, and was first released into the Botanical Gardens in Sydney (Bayly and Williams 1973; McKay 1984). In 1926, the Chief Health Inspector of the City of Sydney established wild populations from specimens imported from another introduced location, Italy (Wilson 1960; Clarke *et al.* 2000). Gambusia was introduced to other parts of NSW from 1927 onwards until World War II, when it was widely established in the state. Until about 1930, city and Municipal Councils distributed fish in the Newcastle and northern coastal regions (Wilson 1960). In 1940, gambusia were flown to Darwin. During World War II they were spread through military camps in many parts of Australia (Myers 1965; Boulton and Brock 1999). Gambusia are reported to have been released into some parts of NSW for the purpose of mosquito control, eg in the Illawarra and Central Coast areas as late as the 1960s (Ross Wellington pers. comm.).

## 5.2 Mosquito Control – Success or Failure?

During the early 1900s, after it was discovered that mosquitoes transmit both malaria and the deadly yellow fever, public health officials and doctors worldwide began to show an interest in reducing or eradicating those diseases by attacking mosquito at their larval stages (Myers 1965; Boulton and Brock 1999). Many attempts have been made to reduce the problems caused by mosquitoes, with many mosquito control options suggested, including physical and chemical methods. The search for a natural control method for mosquitoes led to the concept of biological control (Lloyd 1990a).

Gambusia was first used in 1905 as a mosquito control agent, when specimens from Texas were released in Hawaii (Krumholz 1948; Wilson 1960). Public health authorities were delighted by the hardiness of the so-called ‘mosquitofish’ and the ease with which it spread (Boulton and Brock 1999). American research on mosquito-destroying fishes was thus concentrated mostly on the mosquitofish, which gradually became known throughout the world as THE fish to introduce in the fight against mosquito-transmitted diseases (Myers 1965).

Wilson (1960) emphasises the general opinion of many people at the time in Australia that gambusia was successful in controlling mosquitoes. He stated that gambusia was of distinct value as a mosquito control agent, which exerts good control of mosquitoes in permanent pond habitats. However, Wilson (1960) also considered that the use of gambusia in Newcastle and the north coast of NSW was unsuccessful.

Since 1982, the World Health Organisation (WHO) has no longer recommended the use of gambusia for malaria control programs and indicates that it should not be introduced into new areas, primarily because of its apparent harmful impact on native fish species (Legner 1996).

Views on the effectiveness of gambusia as a mosquito control agent vary. Lake (1971), for instance, stated "I believe their effect on mosquitoes has been negligible". Grant (1978) noted that it was arguable whether gambusia offers better mosquito control than some native fish. Studies in Australia indicate that gambusia is not an effective mosquito predator, with mosquitoes only making up a small part of its diet (Lloyd 1984; Lloyd 1986). In another study in the lower River Murray, only 10% of the diet of gambusia consisted of mosquito larvae, whereas four endemic fish species consumed more mosquitoes (Lloyd 1986; Arthington and Lloyd 1989). Reddy and Pandian (1972) found heavy mortalities of gambusia reared on a diet restricted to mosquito larvae, and the few survivors showed poor growth and delayed maturation.

Several authors have observed that gambusia may actually encourage mosquito populations by preying on their invertebrate predators (Stephanides 1964; Hoy *et al.* 1972; Hurlbert *et al.* 1972; Hurlbert and Mulla 1981). Gambusia are inappropriate for mosquito control in certain habitats such as temporary ponds, waters with dense vegetation and running waters. It is also unlikely to be effective as a predator on cool cloudy days, where drops in temperature and oxygen occur (Lloyd 1986). 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).

## 5.3 Dispersal of *Gambusia*

Gambusia can be spread either directly or indirectly by humans, naturally through floods, or perhaps by other animals such as birds feeding on and regurgitating small fish, dropping them in flight, or transporting fish on mud adhered to their plumage and feet. Lloyd (1987) states that humans were the major dispersal agents of gambusia. McKay (1984) also observed that past records of gambusia around Alice Springs were probably a result of the release of aquarium fish.

The NPWS is not aware of any local councils or health authorities in NSW currently advocating the introduction of gambusia as a mosquito control agent. However, individuals from the public, without realising the impact that the species has on the environment, may still move these fish around, believing that gambusia are efficient at removing mosquito larvae from waterways or simply to dispose of unwanted fish. Some argue that gambusia are safe when used in the “contained” and artificial environments in which they are often stocked, and will not escape to the wild (Meffe 1996). It is also likely that some people move gambusia around believing them to be native species (Ross Wellington pers. comm.).

Flooding of waterways is another potential mechanism for the dispersal of gambusia. One example, is the Brisbane flood of January 1974, which caused widespread flooding of suburban creeks and a number of outdoor ponds and indoor aquaria, which resulted in fish being liberated (McKay 1984). Most outdoor ponds, which are thought to be secure environments, are not fitted with an outlet screen to prevent the discharge of aquarium fish into storm water drains (McKay 1984). Down-stream ponds in particular are prone to reinfection by gambusia sourced upstream during flooding events.

Gambusia has been known to spread from overcrowded pools into wheel ruts or puddles after heavy rainfall (Serventy and Raymond 1980; Wager 1995a). In one reported case a number of fish were found 275 m from the parent lake, swimming along the tiny stream formed by a wheel rut (Serventy and Raymond 1980).

Lloyd (1987) observed that the distribution of gambusia in isolated waterbodies in central Australia was almost certainly a result of flooding. Gambusia are known to be present in artificial water bodies on the Nullabor Plain (Serventy and Raymond 1980; Boulton and Brock 1999). Irrigation channels could be a potential source of infestation of gambusia into nearby creeks and rivers. Wager (1995a) found gambusia to be common in artificial habitats such as bore drains and the wetlands associated with some flowing bores in the Diamantina River Catchment in western Queensland. These artificial habitats probably act as point sources for the ongoing infestation of surrounding water bodies (Wager 1995a). Gambusia has been recorded in several floodplain waterholes in the Cooper Creek drainage (Angela Arthington, pers. obs.).

Lloyd (1984) indicated that adults do not move beyond their home range although they can undertake small scale thermal migrations within this area, while it has been noted that juveniles tend to migrate away from adult populations (Lloyd 1986).

# 6. Biology and Ecology of *Gambusia*

## 6.1 Distribution

In Australia, gambusia are found in at least eight of the eleven major drainage divisions (Merrick and Schmida, 1984). The species is considered to be widespread and common throughout NSW, South Australia and Victoria in both inland and coastal drainages. It is common in coastal drainages of Queensland, is present in rivers draining into Lake Eyre, in parts of the Northern Territory and Western Australia, but has not been recorded from Tasmania (Allen 1989; McDowall 1996; Arthington *et al.* 1999). Arthington *et al.* (1999) observed that the species occurs in most aquatic habitat types in south-eastern Australia.

Although there have been no systematic targeted surveys for gambusia in NSW, there have been a number of surveys, which have identified its presence. The most comprehensive fish survey undertaken has been the NSW Rivers Survey, during which 80 sites were surveyed over four periods from 1994 to 1996. Gambusia were recorded at 27 sites (see Appendix 2) with six sites having captures or observations of more than 50 individuals (Faragher and Lintermans 1997). They were most widely distributed in the Darling and North Coast regions. Gambusia were also recorded at four sites in the South Coast and two sites in the Murray regions (Faragher and Lintermans 1997). They were also found at altitudes of 20 to 1120m, although the majority of sites were below 300 m (Faragher and Lintermans 1997).

Other surveys of fish in NSW include records of gambusia, at the Darling River anabranch (Callanan 1984) and in the Darling River (Callanan 1985), Wingecarribee River (Burchmore *et al.* 1990), Pindari Dam enlargement, Severn and Macintyre Rivers (Swales and Curran 1995), the Macquarie River and its tributaries in the area of the Macquarie Marshes (Swales and Curran 1995a), the Cudgegong River (Swales *et al.* 1993), Gol Gol Swamp (Brown 1994), the Hawkesbury-Nepean River system (Gehrke *et al.* 1999) and lower Balonne floodplain and Narran River (Mottell 1995). Lewis and Goldingay (1999) recorded gambusia at nine of fifteen coastal sites surveyed between Red Rock (40 km north of Coffs Harbour) and Ocean Shores (15 km north of Byron Bay). Gambusia has also been observed in numerous areas at Lake Macquarie on the Central Coast and in the Illawarra catchment and Sydney basin (Ross Wellington pers. comm.; Arthur White pers. comm.; Goldingay and Lewis 1999).

While records of gambusia in the south coast area of NSW are limited, this does not necessarily mean that the species does not occur there. The presence of gambusia in the Snowy River catchment in Victoria was recorded during a survey of the lower Snowy River (Raadik *et al.* 2001). Recent surveys by Daly and Senior (2001) for the green and golden bell frog on the far south coast of NSW, between Batemans Bay and Eden, detected gambusia at 15 of the 115 sites surveyed.

#### *6.1.1 Factors influencing distribution*

Factors influencing the distribution of gambusia in NSW include those directly and indirectly associated with humans, and also natural events such as dispersal through floods, via other animals, and those biological features of the species, which assist its dispersal in nature. Courtenay and Meffe (1989) suggested that gambusia fit seven of the criteria of a successful invader (identified by Ehrlich 1986) as follows:

- are abundant in original range
- are polyphagous
- have a short generation time
- a single female can colonise a new site
- have a broad physical tolerance
- are closely associated with humans, and
- have high genetic variability

Courtenay and Meffe (1989) proposed two additional criteria for success:

- specialised reproduction (ie high fecundity, highly developed young, reproduce numerous times per year, young are independent of adults after birth, the species is tolerant of broad range of temperature and day-lengths)
- females are extremely aggressive often causing the death of other species (Meffe 1985)

## 6.2 Habitat Preferences

Gambusia inhabit rivers, creeks, lakes, swamps and drains and occurs in both clear and muddy water (Cadwallader and Backhouse 1983). It has been able to invade a wide range of habitats including turbid, silty lower reaches of rivers, swamps, lakes, (including salt lakes and dystrophic systems of very low productivity in coastal dunes), billabongs, thermal springs, farm dams, the cooling pondage of a power station and ornamental ponds in many urban parks (Lloyd 1984; Lloyd *et al.* 1986; Arthington and Marshall 1999).

Undisturbed lotic (ie flowing systems) with naturally variable discharge regimes are not favoured by gambusia. High river discharges almost eliminate populations (Meffe 1984; Arthington *et al.* 1990; Galat and Robertson 1992), perhaps because predatory efficiency is low, and long-term survival impossible (Reddy and Pandian 1974; Mees 1977; Lloyd *et al.* 1986). Reddy and Pandian (1974) for example observed gambusia to be less efficient at preying on mosquito larvae in flowing waters.

Gambusia has an ability to withstand adverse conditions, sometimes far beyond their normal tolerances. Lloyd (1984) noted that this enables gambusia to persist (though perhaps without breeding) in an unfavourable habitat before colonising other habitats. In laboratory experiments using gambusia, calm water was found to be the most important habitat variable, followed by submerged vegetation cover, which provides concealment from predators. Dense surface vegetation appears less favourable as it obstructs access to surface water where it forages. These laboratory preferences indicate that gambusia actively seeks a suitable habitat in which it can compete successfully and be protected from predatory birds and fishes (Casterlin and Reynolds 1977; Lloyd *et al*. 1986).

Gambusia are abundant in warm slow-flowing or still waters amongst aquatic vegetation at the edge of waterbodies in water depths of 10 cm or less (Merrick and Schmida 1984; McDowall 1996; Faragher and Lintermans 1997; Arthington *et al.* 1999). They generally prefer warm water temperatures (>25°C) (Lloyd 1984; Clarke *et al.* 2000), showing a thermal preference for water of 31°C and thermoregulate during the day by moving from deep to shallow water (Winkler 1979). Populations are able to withstand wide temperature ranges from just above freezing (0.5°C), to a critical thermal maximum of 38° (Lloyd 1984; Lloyd *et al.* 1986; Clarke *et al.* 2000). Populations have been known to survive for short periods of time in water temperatures as high as 44°C (Lloyd 1984). Young gambusia are more resistant than adults to high temperature allowing them to colonise and exploit warm patches in the environment (Lloyd 1984). Females also appear to show more resistance to high water temperatures than males (Winkler 1975 cited in Lloyd *et al.* 1986).

Luna (2001) noted that the species tolerated a pH range of between 6.0 and 8.8, whereas Swanson *et al.* (1996) noted that a broader pH range of between 4.46 to at least 10.2 is tolerated based on both laboratory tolerance experiments and field observations. Additionally, Knight (2000) has observed gambusia occupying waters of pH 3.93.

#### *6.2.1 Use of modified habitats by Gambusia*

Lloyd (1984) suggested that modified habitats are particularly susceptible to invasion by gambusia due to these areas having relatively abundant sources of food, and low species richness because of harsh physical conditions. Arthington *et al.* (1990) developed this idea with examples from around Australia. The following summary identifies those aspects of habitat modification likely to be favoured by gambusia.

***River Impoundment***

Impoundment of water by dams or weirs can lead to reduced water discharge and slower flows. The subsequent development of shallow littoral zones, pools and areas of lentic habitat can facilitate growth of fringing vegetation. Such areas can provide very favourable habitat for gambusia. Arthington *et al.* (1983) observed that the proliferation of gambusia in the waterways of urban Brisbane corresponded to human induced changes, including construction of water-supply dams and flood retention basins, diversion of stream channels for flood mitigation, excavation of sand and gravel to form lentic habitat.

***Bank, riparian and channel alterations***

Degradation of riparian areas through agricultural and pastoral practices may lead to loss of riparian vegetation, bank erosion and collapse, sedimentation and river-bed alterations. These are conditions which gambusia can tolerate to the disadvantage of native species (Arthington *et al.* 1990).

***Water quality and pollution***

Arthington *et al.* (1990) argue that the ability of gambusia to tolerate low dissolved oxygen concentrations has probably enabled the species to survive in areas such as stagnant urban drains, enriched ponds and eutrophic impoundments. Gambusia are able to utilise oxygen-rich surface layers of water, enabling them to survive in anoxic situations due to their dorsally-oriented mouth and flattened head (Lloyd 1984).

Lloyd (1987) reviewed the tolerance of gambusia to pollutants and observed that the species was resistant to a wide range of pollutants, including organic wastes, phenols, pesticides, heavy metals and radiation. He observed that the species tolerance and resistance to pesticides is well known as it had been used in combination with pesticides to control mosquito larvae in rice fields in the United States.

Gambusia are tolerant of a wide range of salinities, from very low salinity fresh water to marine conditions (McDowall 1996; Arthington and Lloyd 1989). Gambusia generally tolerate salinities of 25g/L in the field in the United States, but have been recorded in

Australian salt lakes with salinities of 30g/L. Under laboratory conditions, most gambusia can tolerate salinities of 50g/L and some can survive 80g/L salinity conditions for short periods (seawater has a salinity of 35g/L) (Lloyd 1984).

## 6.3 Breeding Biology, Social Organisation and Dispersal in Nature

***Sexual maturity***

Gambusia grow rapidly, becoming sexually mature in less than two months (McDowall 1996). Immature male gambusia are sexually active well before their copulatory organ (gonopodium) has completely developed and before they are able to transfer sperm (Bisazza *et al* 1996).

***Fecundity***

Sexually mature females have been recorded as having up to nine broods a year from about August to April (Milton and Arthington 1983; McDowall 1996). On average, females have two or three broods per season, and store sperm between breeding seasons (Howe 1995; Lund 1999a). Female gambusia may store sperm for up to eight broods or eight months and may nourish the live sperm within their reproductive tracts (Constantz 1989). Peak reproductive activity occurred in October in a population of gambusia studied near Brisbane, with 94% of females being pregnant at that time (Milton and Arthington 1983). The reproductive cycle is primarily governed by photoperiod, with reproduction ceasing once day length falls below 12.5-13 hours, even when water temperature remains favourable (Lloyd 1986; Milton and Arthington, 1983; Pen and Potter 1991). Gambusia are live bearers (i.e viviparous), with fertilisation occurring internally and the embryos developing within the female (Cadwallader and Backhouse 1983; McDowall 1996). The gestation period is between 21 and 28 days, with about 50 young being produced on average, though broods may often exceed 100, with more than 300 having been reported in a single brood (Cadwallader and Backhouse 1983; Milton and Arthington 1983; McDowall 1996).

***Survivorship***

While the approximate sex ratio of young gambusia is initially 1:1, the subsequent higher mortality in males results in females usually dominating the adult population (Cadwallader and Backhouse 1983; Vargas and de Sostoa 1996). Males tend to disappear from populations, which may be due to their reproductive efforts and male fish being more susceptible to overcrowding and temperature stress than the females (Krumholz 1948 cited in Vargas and de Sostoa 1996). When female gambusia are pregnant their morphology changes and slower movements may render them more visible and therefore more susceptible to predators, skewing the sex-ratio in favour of males at this time (Vargas and de Sostoa 1996). The maximum life span of up to two years occurs in females that do not mature until their second summer (Cadwallader and Backhouse 1983), although most will perish during winter (Lund 1999a).

***Social organisation including behavioural characteristics***

Gambusia display a wide range of behaviours which enable them to adapt to a variety of situations (Lloyd 1984). In a study of the impacts of gambusia on the southern blue-eye (*Pseudomugil signifer),* no documented evidence of territoriality was found for gambusia. Territorial behaviour has not been observed in the family Poeciliidae of which gambusia is a member (Howe 1995). However, gambusia is known to show aggressive behaviour towards other fish species such as the southern blue-eye (*P. signifer)* (Howe 1995). Bisazza *et al.* (1996) found in experimental trials that adult males showed aggressive behaviour towards another male attempting copulation, irrespective of the maturity of the latter. The aggressive behaviour of gambusia toward fish species is discussed in detail in section 7.3.

## 6.4 Diet and Factors Influencing Dietary Preferences

Gambusia is an opportunistic omnivore with a preference for animal food (Rosen and Mendelson 1960; Al-Daham *et al.* 1977; Farley 1980 cited in Lloyd *et al.* 1986). Gambusia select their prey according to size, colour, movement (Bence and Murdoch 1986; Lloyd *et al*. 1986) position in the water column (Arthington and Marshall 1999) and availability (Lloyd 1984). Arthington (1989) found that gambusia preferred small prey, a finding consistent with that of Bence and Murdoch (1986) who investigated size-selective predation by gambusia. These two studies conflict with field studies by Wurtsbaugh *et al.* (1980) who suggested that gambusia generally select the largest prey they can successfully capture.

Gambusia feeds on a diverse range of terrestrial insects such as ants and flies that fall onto the water's surface, as well as aquatic invertebrates including bugs, beetles, fly larvae and also zooplankton (Lloyd *et al.* 1986; Arthington 1989; McDowall 1996). It is an adaptable generalist predator, able to vary its diet according to prey availability (Arthington 1989; McDowall 1996). Gambusia are diurnal visual feeders that feed during daylight hours and rely on sight to detect, track and attack prey (Swanson *et al.* 1996). In a study by Arthington and Marshall (1999) they found the diet of gambusia was composed of aquatic invertebrates, filamentous algae, terrestrial insects, arachnids, fragments of fruit and other plant tissues. More than 50% of the diet comprised items found at the water's surface, such as chironomid pupae (midges), arachnids and terrestrial insects.

There is no direct evidence that frog eggs or tadpoles form a natural component of the diet of gambusia (Reynolds 1995), although the impact of gambusia on native frogs has been studied (eg Reynolds 1995; Morgan and Buttemer 1996; Webb and Joss 1997; Healey 1998; Gillespie and Hero 1999; Komak and Crossland 2000; Pyke and White 2000). Refer to section 7.4 for more information regarding the impacts of gambusia on frogs.

## 6.5 Known and Potential Diseases, Predators and Competitors

***Disease and Parasites***

Gambusia has relatively few parasites in Australia when compared to North America (Lloyd 1990). Swanson *et al.* (1996) has prepared a list of 23 of the most common and important parasites and pathogens of gambusia in the U.S.A. The only parasite observed on gambusia in the lower Murray River (South Australia) is an exotic parasitic copepod, *Lernaea cyprinacea* (Lloyd 1984; Arthington and Lloyd 1989; Lloyd 1990). Another introduced parasite found in gambusia is a protozoan, *Goussia piekarskii* (Lom and Dykova 1995). Dove (1998) noted that 11 parasites have been recorded in gambusia in Queensland.

***Predators***

In North America, predatory fish, wading birds, snakes and invertebrates have been found to prey on gambusia (Meffe and Snelson 1989). Swanson *et al.* (1996) list major predators of gambusia in the USA, as migratory and resident birds (herons, egrets, bitterns, grebes, ducks, kingfishers, terns, crows and blackbirds), piscivorous fishes (sunfish, catfish, bass), bullfrogs, and some aquatic insects including notonectids (backswimmers), corixids (water boatmen), dytiscids (predaceous diving beetles), and larval anisopterans (dragon flies).

Predators of gambusia in Australia probably include birds, fish and even spiders (Lloyd 1984). Many of the major predators of gambusia in the USA listed in Swanson *et al*. (1996) are also possible predators in Australia. Lloyd *et al.* (1986) noted important fish predators to include species of *Anguilla, Mogurnda, Gobiomorphus, Leiopotherapon* and *Glossamia*, although their impacts on gambusia are not known. Lloyd (1987) noted that water rats *Hydromys chrysogaster* and the fish eating bat *Myotis adversus* also apparently fed on gambusia. There have been very few studies of predators of gambusia in Australia, but there have been suggestions as to the likely cause of low predation levels (Lloyd 1984). Both native and exotic fish predators avoid gambusia as prey when given a choice (Lloyd 1984; Lloyd 1990). Reports suggest gambusia are considered unpalatable and that native predators may not have evolved behaviours appropriate to the capture of gambusia (Lloyd 1984). In inland lakes of NSW, little black cormorants (*Phalacrocorax sulcirostris)* feed mainly on exotic fishes such as carp and gambusia (Boulton and Brock 1999). Lloyd (1984) noted that, when exposed to predators, gambusia can rapidly develop complex escape and avoidance behaviours.

***Competitors***

Native fish species may compete with gambusia for food or other resources. Section 7.3 includes discussion of the theory of competition in relation to gambusia and other species. Extensive dietary overlap occurs between gambusia and a number of native species.

# 7. Impacts of *Gambusia* on Native Plants and Animals

## 7.1 Impacts on Native Vegetation and River Health

No forms of direct physical disturbance to aquatic environments, including to aquatic vegetation, appear to have been attributed to gambusia. The species does not exhibit obvious behaviours (such as carp disturbing aquatic vegetation while feeding), which may lead to habitat degradation.

## 7.2 Impacts on Macro-invertebrates

Few studies have been undertaken concerning the impact of gambusia on invertebrates and the impact on threatened Australian invertebrates is not currently known. There is some evidence that gambusia can cause reductions in populations of invertebrates such as rotifers, cladocerans, ostracods, copepods, mayflies, beetles, dragonflies and molluscs (Hurlbert *et al.* 1972; Lloyd 1990a; Lund 1999b; Anstis 2002).

Declines in some invertebrates may cause an increase in phytoplankton populations (Lloyd 1990a). Stephanides (1964 cited in Hurlbert *et al.* 1972) observed a dramatic top-down effect of introducing gambusia to a small lake where fish had previously been absent; the elimination of zooplankton by gambusia caused a tenfold increase in phytoplankton populations. Gambusia may change invertebrate assemblages of ponds by differential predation, which can make a system unstable (Lloyd 1984). Lund (1999b) argued that these fish could potentially reduce water quality and could also increase the amount of algae in the water through excretion of nutrients. He suggested that in more pristine environments gambusia may eliminate rare taxa. In relation to mosquito control, Lloyd *et al.* (1986) argued that at low densities gambusia may actually encourage mosquito larvae by eating their invertebrate predators in preference to mosquitoes.

Ecological attributes of macroinvertebrates that would make them susceptible to population level impacts from gambusia may include their method of reproduction, dispersal and migratory habits. Aquatic insects that have a terrestrial stage may be susceptible to predation by gambusia when undergoing the emergence stage of their life cycle (eg chironomid pupae - Arthington and Marshall 1999). Insects that deposit eggs on the water's surface may be susceptible to predation by gambusia if this occurs during times of the year when gambusia are at peak abundances.

## 7.3 Impacts on Native Fish

***Worldwide Impacts***

Some thirty-five fish species worldwide have declined in abundance or range as a result of interactions with gambusia (Lloyd 1990). Lloyd (1987) provides a list of these species. Arthington and Lloyd (1989) considered that gambusia have been implicated in the extinction of small fish species in the USA, Asia and Africa and in the reduction in range or abundance of twenty-five species in the worldwide. In the USA, the replacement of a native fish species, the Sonoran topminnow (*Poeciliopsis occidentalis)* by gambusia is well documented (Galat and Robertson 1992). This native species was once widespread and abundant in desert areas and is now considered threatened due to habitat loss and predation by gambusia.

***Impacts on Australian Species***

While no local extinctions of fish species have been attributed to gambusia in Australia, this species may influence the distribution and abundance of particular native fish in areas where they co-occur (Arthington and Lloyd 1989). Howe *et al.* (1997) concluded that the ubiquity of gambusia has major implications for the conservation of several smaller species of fish in

Australia. In association with a range of environmental alterations, gambusia are thought to have played a role in the decline of fish species from six genera in Australia: *Mogurnda*, *Ambassis*, *Melanotaenia*, *Pseudomugil*, *Craterocephalus* and *Retropinna* (Arthington *et al*. 1983; Lloyd 1990). However, Lloyd (1990) cautioned that much of the evidence was circumstantial and patchy.

Lloyd (1984) argued that there is extensive overlap in requirements for food and space where populations of native fish and gambusia co-occur, and Arthington *et al.* (1983) demonstrated this in streams. Extensive dietary overlap has been documented between gambusia and at least seven native fish species, while two native species also show shifts in feeding niches, through expanding their feeding preferences, when living in association with gambusia (Lloyd 1990). Arthington and Marshall (1999) observed high dietary overlap between gambusia and the native ornate rainbowfish (*Rhadinocentrus ornatus),* and moderate dietary overlap with the native fire-tailed gudgeon (*Hypseleotris galii).* At some times of the year, gambusia switched its diet to feed on aquatic invertebrates usually eaten by these gudgeons, which increased the dietary overlap between the two species.

In some areas of eastern Queensland, gambusia can dominate fish assemblages and may reduce the abundance and diversity of native species. McKay (1984) observed that in Queensland coastal streams where gambusia, guppies and swordtails occurred, native surface feeding or mosquito eating fish such as *Melanotaenia*, *Pseudomugil*, *Craterocephalus* and *Retropinna* were usually rare or absent. He noted the example of a significant decline in the southern blue-eye *(P. signifer)* at a site in the Brisbane River five years after gambusia and guppies had invaded.

In creeks in the Brisbane area, Arthington *et al.* (1983) observed that large numbers of gambusia were correlated with small numbers of the native fire-tailed gudgeon (*H. galii)* and crimson-spotted rainbowfish (*Melanotaenia fluviatilis),* and that where they occurred together encounters were very likely. Arthington *et al.* (1983) noted that while the small populations of crimson-spotted rainbowfish *(M. fluviatilis)* may have been caused by habitat disturbance, the relationship between gambusia and fire-tailed gudgeon (*H. galii)* may have been due to interactions between these two species. They suggested that the importance of interactions such as competition and predation may vary with the size structure of populations.

There is some evidence of predation and aggression by gambusia on native species. Investigation of gut contents of wild gambusia in NSW identified juveniles of Australian smelt, Duboulay's rainbowfish (*Melanotaenia duboulayi)*, ornate rainbowfish (*R. ornatus),* southern blue-eye (*P. signifer*) and fire-tailed gudgeon (*H. galii*) (Ivantsoff and Aarn 1999). Fish remains were only identifiable up to 4 hours after feeding, which suggests that gut analyses may often underestimate many food items. Ivantsoff and Aarn (1999) noted that their study could not identify the significance of predation on native species by gambusia as newly hatched fish may be an important food source for fish species. In tank experiments, Howe (1995) observed gambusia to actively hunt and eat the young of southern blue-eye. Aarn (1998) suggested that in marginal eutrophic habitats where gambusia breed during the warmer months, high levels of predation of eggs and larvae may lead to the extinction of melanotaeniids (rainbow fishes). During monitoring of populations in January, in springs in central western Queensland, Wager (1995) suggested that the absence of juvenile red-finned blue-eyes (*Scaturiginichthys vermeilipinnis)* was probably due to predation of their eggs or fry by gambusia.

Gambusia can exhibit aggressive behaviour towards other fish, including those much larger than themselves. This behaviour includes harassment such as chasing and fin-nipping, which may be so severe that fins are entirely removed (McKay 1984; Unmack and Brumley 1991; Steve Saddlier pers. obs.). In some instances, aggressive behaviour may also lead to secondary bacterial or fungal infections and eventual death (Faragher and Lintermans 1997; Knight 1999). Stress caused by aggression may also reduce breeding success as well as feeding and metabolic processes (Howe *et al.* 1997).

Howe *et al.* (1997) argued that fin nipping may only occur in crowded conditions, such as with receding tides or prolonged drought conditions, where large numbers of fish occur in small ponds and waterholes. Howe *et al.* (1997) also suggested that the aggressive interactions observed may be a form of interspecific competition for space. Knight (1999) investigated interference competition between southern blue-eye (*P. signifer*) and gambusia. He found that under captive conditions, interference competition was density dependent and that gambusia inflicted stress and physical damage to the blue-eyes. Variations in aggressive behaviour were observed between individual fish, and males tended to attack more often than females. Further experiments under captive conditions have shown gambusia to exhibit aggressive behaviour towards ornate rainbowfish, (*R. ornatus)* Duboulay’s rainbowfish (*M. duboulayi)* and firetailed gudgeon (*H. galii*) (Jamie Knight pers. comm.).

Lloyd (1990) indicated that there was some evidence that gambusia could affect growth rates of native fish species. In tank experiments, gambusia significantly affected both the growth and reproductive characteristics of southern blue-eye (*P. signifer*)(Howe *et al.* 1997). They found that fish did not gain weight or grow in total length, their ovarian weight and fecundity were greatly reduced, and their ovaries were morphologically undeveloped. These results clearly indicate that gambusia has the potential to significantly affect reproductive success as well as survival of this native species in confined habitats (Howe *et al.* 1997).

Koster (1997) undertook tank experiments to determine whether gambusia affected the growth of native southern pygmy perch. His results indicated that under controlled conditions where food was not a limiting factor, gambusia did not affect the growth of the native species. In these tanks, gambusia nipped the fins of the southern pygmy perch as well as those of dwarf galaxias. However, this did not result in any infections or deaths of the native fish. Breen *et al.* (1989) also noted a total overlap in the diets of gambusia and dwarf galaxias.

In some countries, hybridisation has occurred between gambusia species (Lloyd 1986). Howe (1995) points out that hybridisation between gambusia and native fish species is not possible as gambusia are live-bearers rather than egg laying fish.

***Impacts on Threatened Fish Species in NSW***

The NSW Fisheries Scientific Committee has identified gambusia as a possible cause of decline for the following threatened fish:

- Oxleyan pygmy perch (*Nannoperca oxleyana)* (Endangered species)
- Murray hardyhead (*Craterocephalus fluviatilis)* (Endangered species)
- Silver perch (*Bidyanus bidyanus)* (Vulnerable species)
- Western population of southern purple-spotted gudgeon (*Mogurnda adspersa)* (Endangered population)
- Western population of olive perchlet (*Ambassis agassizii)* (Endangered population)

## 7.4 Impacts on Native Frogs

Predation is generally recognised as a major factor regulating the distribution of amphibian tadpoles (eg Calef 1973; Heyer *et al.* 1975; Duellman 1978; Scott and Limerick 1983; Smith 1983; Woodward 1983; Wilbur 1984; Hayes and Jennings 1986; Kats *et al.* 1988; Gillespie 2001). Predatory fish are important determinants of tadpole species-composition (ie proportions of species present) and tadpole species richness (ie total number of species present) in both temperate (Hecnar and M'Closkey 1997) and tropical systems (reviewed by Gillespie and Hero 1999). Many frog species avoid predation from fish by reproducing in habitats inaccessible to them, such as ephemeral pools or terrestrial microhabitats. Amphibian species that do reproduce in habitats naturally containing predatory fish invariably possess one or a combination of survival strategies to evade predation (Kats *et al.* 1988), such as cryptic colouration (Wasserug 1971), behavioural responses such as use of refugia (Sih *et al.* 1988), schooling (Waldman 1982; Kruse and Stone 1984) and chemical defences (Liem 1961; Wasserug 1971; Brodie *et al.* 1978; Kruse and Stone 1984; Kats *et al.* 1988; Werner and McPeek 1994).

Survival strategies tend to be predator specific and are unlikely to be effective against all predators. Palatability of a species of tadpole is not constant, varying according to the predatory fish species (Hero 1991; Holomuzki 1995; Gillespie 2001). Therefore, the distribution of each tadpole species is related to the survival strategies it possesses and is strongly influenced by the distribution of predatory fish (Gillespie and Hero 1999).

Tadpoles of native species may be able to evade predators with which they naturally coexist but may be unable to evade an introduced or new predator. These species may not identify such fish as predators and hence fail to use the appropriate survival strategies (temporal or spatial isolation), or may not have the necessary anti-predator defences (eg cryptic colouration, behavioural responses such as refugia, schooling and chemical defences) that allow them to coexist with introduced fish species (Gillespie and Hero 1999; Gillespie 2001; Hamer *et al*. 2002). The introduction of a predatory fish species may result in the local or total extinction of some native prey species and a shift in the species composition of native frogs to those species, which have the survival-strategies that allow them to coexist with the introduced predator (Gillespie and Hero 1999).

The consequences of introducing fish into breeding habitats for frogs have been well documented overseas. A number of studies in Europe, North and South America have implicated or demonstrated that introductions of predatory fish are responsible for the decline or extinction of some frog species (see Gillespie and Hero 1999).

Several studies in USA have demonstrated predatory impacts of gambusia on amphibians. Gamradt and Kats (1996) found that gambusia contributed to localised population declines of California newts (*Taricha torosa)* through predation on their larvae. Goodsell and Kats (1999) found that gambusia preyed heavily on tadpoles of Pacific tree frogs (*Hyla regilla)*, both in natural streams and laboratory experiments, despite the presence of high densities of mosquito larvae as alternative prey.

Gambusia may impact upon amphibian populations directly and indirectly by:

- predation of eggs and hatchlings
- predation of tadpoles
- aggressive behaviour causing tadpole tail damage or loss, which can result in increased risk of disease, increased risk of predation by other predators because of loss of mobility and reduced energy reserves and growth rates resulting in poorer post-metamorphic fitness
- aggressive behaviour causing changes in microhabitat use and activity patterns of tadpole, resulting in increased risk of predation by other predators or reduced growth rates

The broad distribution and wide range of habitats occupied by gambusia in Australia means that this species may potentially impact upon many lentic and lotic frog populations over a large region. Gillespie and Hero (1999) reviewed the literature on interactions between gambusia and Australian amphibians. The following discussion is taken from this review, with the addition of more recently published information:

A number of studies have identified negative associations between the presence of gambusia and frog species. Dankers (1977) found that tadpole numbers of several species were drastically reduced in ponds containing gambusia after early December in NSW, coinciding with a seasonal increase in fish biomass. McGilp (1994) found a negative correlation between the occurrence of the brown tree frog (*Litoria ewingii)* and that of gambusia in waterbodies along the Yarra River in Melbourne, Victoria.

Reynolds (1995) found eggs of the sign-bearing froglet (*Crinia insignifera)* and Glauert's froglet (*Crinia glauerti)* to be unpalatable to gambusia. Preliminary trials also suggested that eggs of the slender tree frog (*Litoria adelaidensis)*, Moore's frog (*Litoria moorei)* and Tschudi's froglet (*Crinia georgiana*) may also be unpalatable (Reynolds 1995). However, several studies have shown experimentally that gambusia are capable of preying on hatchlings and small tadpoles of a number of Australian frog species, such as the spotted grass frog (*Limnodynastes tasmaniensis),* Leseuer's frog (*Litoria leseueuri)* and bleating tree frog (*Litoria dentata)* (Harris 1995), sign-bearing froglet (*C. insignifera*) and Glauert's froglet (*C. glaureti*) (Reynolds 1995), green and golden bell frog (*L. aurea)* and bleating tree frog (*L. dentata*) (Morgan and Buttemer 1996), striped marsh frog *Limnodynastes peronii* and sign-bearing froglet (*C. insignifera*) (Webb and Joss 1997).

Blyth (1994) compared survival and recruitment of tadpoles of three species of Western Australian frogs, Glauert's froglet (*C. glaureti*), sign-bearing froglet (*C. insignifera*) and moaning frog (*Heleioporus eyrei),* in the presence and absence of gambusia in experimental field enclosures. Tadpole survival of all species was significantly lower in the presence of gambusia at the end of the experimental period. However, the design of the enclosures allowed access for breeding by frogs from local frog populations, as evidenced by increases in numbers of frogs in some enclosures. Other potential predators of tadpoles also had access, such as invertebrates and birds. Furthermore, no species/fish treatments were replicated. These factors limit interpretation of the results of this study.

Webb and Joss (1997) examined frog species richness and abundance in relation to gambusia density and cover of emergent aquatic vegetation in ten ponds near Sydney. They found a significant negative relationship between fish density and frog abundance but no relationship with frog species richness. The descriptions provided for each waterbody indicate high variability in habitat among pond sites. Unfortunately, additional factors such as pool size and native vegetation cover, which may strongly affect frog abundance, were not considered in their analyses. Tadpole density is easier to sample systematically than adult frog density in pond habitats (Heyer *et al.* 1994). Given that tadpoles are one of the life stages upon which gambusia potentially preys, a measure of the relative abundance of tadpoles, rather than that of frogs, may have provided a more reliable indicator of the impact of gambusia.

Reynolds (1995) examined the occurrence of six frog species with gambusia in water bodies near Perth, Western Australia. In contrast to the above studies, he found no relationship between the presence/absence of gambusia and individual frog species, with one exception, the sign-bearing froglet (*C. insignifera*), which was found only infrequently together with gambusia. However, he observed that most of the sites used by the sign-bearing froglet (*C. insignifera*) were ephemeral and unsuitable for gambusia. Frog species richness was generally lower at sites occupied by gambusia, but many of these sites were also degraded, contributing to their unsuitability as frog breeding habitats.

Reynolds (1995) also experimentally examined predation by gambusia on several tadpole species in Western Australia. Trials with tadpoles indicated that gambusia were able to attack and kill tadpoles of the slender tree frog (*L. adelaidensis),* Tschudi's froglet (*C. georgiana*) and moaning frog (*H. eyrei).* Controlled palatability experiments showed that survival of Moore's frog tadpoles was significantly reduced in the presence of gambusia. However, gambusia showed a strong preference for invertebrate prey (*Daphnia* sp. or mosquito larvae). Both groups were consistently consumed completely before tadpoles in all trials. In a field enclosure experiment, in which tadpoles were also exposed to invertebrate predators, Reynolds (1995) found no significant difference in survival in the presence or absence of gambusia. These results, in conjunction with his field survey data, suggest that the impact of gambusia upon populations of these frog species is influenced by several factors, and under natural conditions may be limited.

Webb and Joss (1997) conducted predation experiments examining the impact upon survival of different size classes of sign-bearing froglet (*C. insignifera*) and striped marsh frog (*L. peronii*) tadpoles by hungry and pre-fed gambusia. They found significant differences between predation rates related to tadpole size class and hunger status of fish. Tadpoles of species which are able to rapidly attain moderate to large sizes, may therefore be less predated upon than tadpoles of other species (Caldwell *et al.* 1980; Crump 1984).

Several studies have reported damage to the tails of larger tadpoles from gambusia attack (Dankers 1977; Blyth 1994; Harris 1995). This damage could result in reduced survival of larger tadpoles due to reduced mobility and feeding, inability to escape other predators, or reduced metamorphic fitness. However, some tadpole species have been found to survive tail loss (Harris 1995). Wilbur and Semlitsch (1990) reported tail regeneration by tadpoles of the American bullfrog (*Rana catesbeiana)* even after considerable loss, and suggest that this may be a general mechanism to reduce the impact of predation.

Concerns for the role of gambusia in the decline of some frog species, particularly members of the bell-frog complex, have been expressed by several authors (Mahony 1993, 1999; Daly 1995; Morgan and Buttemer 1996; White and Pyke 1996; White and Ehmann 1997; van de Mortel and Goldingay 1998; Goldingay and Lewis 1999; Lewis and Goldingay 1999; Biosphere Consultants Pty Ltd 2001; Daly and Senior 2001; Hamer *et al.* 2002). However, direct evidence linking gambusia to declines of frog populations in the ‘bell frogs’ is limited, due in part to conflicting findings and methodological limitations of some studies. For example, Morgan and Buttemer (1996) conducted controlled predation experiments examining the impact upon survival of tadpoles of green and golden bell frog (*L. aurea*) and bleating tree frog (*L. dentata*) by gambusia. The influence of aquatic vegetation on the predatory impact of gambusia was also examined. They found that in the absence of aquatic vegetation, gambusia were able to significantly reduce tadpole survival of both species within 24 hours. In the presence of aquatic vegetation, the effect was substantially reduced, and no significant impact of gambusia could be detected on the green and golden bell frog (*L. aurea)* after three days. However, survival of the bleating tree frog (*L. dentata*) was still significantly reduced after two days. These findings indicate that presence of gambusia may significantly influence the survival of tadpoles, but that this is likely to be strongly influenced by habitat structure and tadpole behaviour. Green and golden bell frog *(L. aurea*) tadpoles have also been found occurring with native predatory fish (Graeme Gillespie pers. obs). In the absence of comparative data on the impact of these natural predators upon larval survival, it is difficult to assess the relative ecological significance of gambusia predation.

Pyke and White (1996) surveyed waterbodies in the Sydney region for green and golden bell frogs (*L. aurea*), and examined associations between evidence of breeding, occurrence of introduced fish, and habitat. They found that breeding was most strongly associated with ephemeral rather than permanent or ‘fluctuating’ ponds, followed by the absence of introduced fish, primarily gambusia, and speculated that this fish was a major cause of decline of green and golden bell frogs. However, examination of their data reveals that pond permanency and occurrence of gambusia were highly correlated and so the results could also be explained in terms of unmeasured features of pond permanency and also abundance of other predators.

Hamer *et al* (2002) however, has experimentally demonstrated that the growth of green and golden bell frog tadpoles is more favourable in permanent, rather than ephemeral water bodies and found that tadpoles did not respond to the presence of gambusia, making them more vulnerable to predation. The authors conclude that predation from gambusia may have reduced the suitability of permanent water bodies as optimal breeding habitat for green and golden bell frogs and that the long-term use of less favourable ephemeral habitats may have contributed to the decline of this species.

White and Ehmann (1997) suggested that gambusia was also implicated in the decline of the yellow-spotted tree frog (*Litoria flavipunctata)*, a closely related species to the green and golden bell frog. However, Osborne *et al.* (1996) point out that many of the sites from which this species has disappeared do not contain gambusia. Furthermore, both the green and golden bell frog (*L. aurea*) and southern bell frog (*L. raniformis)* (an ecologically similar species which occasionally hybridizes with the green and golden bell frog (*L. aurea*)) (Watson and Littlejohn 1985), have been recorded in abundance at some sites containing gambusia (van de Mortel and Goldingay 1998; Graeme Gillespie pers. obs.; Ross Wellington pers. obs.).

In the USA, introduced fish have been implicated in the decline of the California red-legged frog (*Rana aurora draytonii*) (Hayes and Jennings 1986). However, Lawler *et al.* (1999) experimentally demonstrated that despite the widespread occurrence of gambusia throughout the former habitat of the California red-legged frog (*R. aurora draytonii*), predation from introduced American bull frogs (*Rana catesbeiana)* was likely to be a more substantial contributor to the decline of this species. In eastern Australia, gambusia are widespread and most abundant in disturbed habitats. To assess the role of gambusia in amphibian declines necessitates uncoupling of the impact of gambusia from other potentially threatening processes.

Christy (2001) experimentally examined the cumulative effects of salinity and gambusia on the survival of tadpoles of the green and golden bell frog (*L. aurea*). She found an interaction between the effects of salinity and gambusia, which was far more detrimental to tadpoles than either factor in isolation. This study demonstrates significant synergistic effects between habitat quality and gambusia, which may have contributed to the decline of the green and golden bell frog (*L. aurea*) and related species such as the southern bell frog (*L. raniformis*).

In summary, gambusia has been shown to kill or injure tadpoles, predate on frog eggs and exert some influence over frog habitat selection. However, conclusive evidence for gambusia having population level impacts on the abundance of Australian amphibians is yet to be clearly determined and is probably complicated by the cumulative effects of other threatening processes occurring at that time. Thus no absolute measure of the impact of gambusia on threatened frogs exists which may be used for prioritising management actions. So for this plan, an objective method for comparing the likelihood of impact between species was derived (Appendix 3). This model will then act as a means for prioritising the allocation of resources to gambusia control.

The likelihood of impact on NSW frogs was modelled by comparing factors related to the susceptibility of a frog species to gambusia predation. These factors were derived from those ecological attributes of frogs, particularly the egg and tadpole stages of the life cycle, that make them potentially vulnerable to impacts from gambusia. Factors included in the model were, habitat use, diet, fecundity, exposure/protection of eggs, length of larval period and anti-predator adaptations. These factors were scored for all threatened and native frogs. Species with high scores are considered to be at higher risk of population level impacts from gambusia.

The model identified four threatened species as most likely to be at risk from gambusia predation (Appendix 3). They are the endangered green and golden bell frog (*L. aurea*), southern bell frog *(L. raniformis)* and yellow-spotted bell frog *(L. castanea)* and the vulnerable wallum froglet (*Crinia tinnula)*. The ‘bell frog’ group of species have been identified by the NSW Scientific Committee determination process as well as by the scientific literature as species likely to be impacted by gambusia. Habitats containing key populations of these species will be considered as high priority for management intervention, including gambusia removal where feasible.

Other threatened species such as the vulnerable olongurra frog (*Litoria olongburensis)* and the Nandewar and New England Bioregion endangered population of tusked frog (*Adelotus brevis)* had lower scores and are considered medium priority for gambusia control. The remaining threatened species had a very low, or zero score from the model and are considered, at this stage, to be a low priority for management.

A number of non-threatened native frog species were also identified as being at higher risk from gambusia predation. They include species in the genera *Litoria*, *Paracrinia* and *Limnodynastes*, in particular the brown tree frog (*Litoria ewingii*), eastern dwarf tree frog (*Litoria fallax*), Perons tree frog (*Litoria peronii*) and *Litoria tyleri*, which are generally regarded as common and widespread in NSW (Appendix 3). For the purposes of this plan, these species will be considered of lower priority for targeted management intervention (ie actions that seek to remove gambusia from key sites) as they are less likely to experience population level impacts from gambusia predation than high risk threatened species. Nevertheless, these species are likely to benefit from the threat abatement actions proposed in the plan.

## 7.5 Benefits to Native Plants and Animals

The presence of gambusia has not been shown to provide any clear benefits to native plants and animals. However, some larger native fishes and birds may occasionally utilise them for food.

# 8. Control of Gambusia

Very few documented control programs have been specifically targeted at gambusia, due mainly to the absence of control methods, which are both effective and specific for gambusia. The only effective control methods kill all fish species present and often other fauna species as well as gambusia. Chemical, biological and physical control measures trialed on gambusia, and other introduced fish such as carp, have been comprehensively reviewed by McKay *et al*. (2001). A brief summary is provided.

***Chemical Control***

Rotenone is a broad spectrum registered pesticide which is used as a garden insecticide. It is produced from the roots of several different plants, most commonly derris root, giving rise to the name 'Derris Dust'. Rotenone has been used to control fish such as gambusia and carp. It can be applied to fish by suspension in water, by injection or by ingestion of an oral bait. In suspended form, rotenone enters the fish through the gills as the fish respire. It is carried through the entire body of the fish and causes the fish to suffocate because oxygen in the blood is not released to the tissues.

Rotenone is not registered as a fish poison in Australia. It is toxic to most fishes and likely to impact on other species such as macro-invertebrates and possibly frogs, particularly at the egg and tadpole stages. It does break down into harmless by-products relatively quickly and has been used successfully in small, enclosed water bodies such as dams, farm dams and ponds (Meronek *et al.* 1996; Koehn *et al.* 2000). Rotenone has potential to be utilised in the creation of gambusia free supplementary habitat for certain frog species such as the green and golden bell frog (*L. aurea*), which utilises small permanent and ephemeral water bodies such as farm dams and ponds as breeding habitat.

Lime and chlorine have also been used to control gambusia. However, neither are registered as fish poisons and both are also non-specific, killing most aquatic organisms. Dose rates and other impacts on non-target species require clarification.

***Biological Control***

Predation of gambusia by larger species is a control method, which is considered as one with high potential in the long-term control of gambusia. There is, however, little (if any) quantitative data available to support this technique under natural circumstances. White (2001) suggested that mouth almighty (*Glossamia aprion)* may be a useful adjunct to fish poisons in eradicating gambusia from warm temperate ponds. Mouth Almighty (*G. aprion)* is a species native to coastal drainages of (possibly) northern NSW, Queensland, Northern

Territory, northern Western Australia and the southern rivers of Papua New Guinea (McDowall 1996). Appropriate stocking levels and potential impacts on tadpoles are not known and there would be significant risks associated with translocating this (and other) predatory species to locations outside of their normal ranges.

Other biological control mechanisms such as the use of parasites, pathogens, bacteria and viruses have been proposed. However, more research is required to assess their effectiveness and impacts on native fauna. Research into molecular biology and biotechnology techniques to produce immuno-contraceptives or artificially enhanced pathogens that either kill or disable target species via the blocking of reproductive mechanisms may provide an effective future control method for gambusia. The Murray Darling Basin Commission is currently funding research into manipulating the genetic structure of carp to produce an inheritable 'daughterless carp' (Murray-Darling Basin Commission 2002). The intent of the research is to reduce the long-term population of carp by restricting offspring to males. This research will initially be trialled on gambusia and therefore may have future benefits to the control of this species.

***Physical Control***

The most effective physical control method is likely to be the draining and drying of isolated habitats of specific frog species and the reduction of water levels to prevent access by gambusia to all or parts of this habitat. This technique is feasible, particularly if the water level in the waterbody or wetland can be easily manipulated and the potential for reintroduction from either upstream or downstream can be controlled. These practicalities will limit the size of waterbodies and wetlands that can be treated. The size and number of watercourses entering the waterbody will also be a significant constraint. Some of these waterbodies and wetlands may also rely on periodic inundation from nearby watercourses, and the feasibility of restricting re-introductions of gambusia from these sources may be limited. The draining of these wetland areas has been used to successfully control gambusia in isolated ponds found in Alice Springs (McKay *et al*. 2001). Although it has been determined that the area must be dried out entirely as gambusia are able to survive relatively harsh conditions with little water for some time.

Restoration of fully functioning ecosystems and ecological processes may be regarded as an indirect method of control. Human induced processes that modify or degrade natural environments can favour the establishment and subsequent domination of introduced species. The reversal of these processes is likely to benefit many native species (Arthington *et al.* 1990). Known habitat preferences of gambusia appear to support this hypothesis. The rehabilitation of ecosystem attributes such as habitat structure, stream bed contours, substrate type, flow regime, water quality, aquatic plants, riparian vegetation and connectivity between habitats should make habitat less favourable to gambusia and more favourable to native fishes. Many species of native fish would therefore be able to compete more effectively with gambusia. Ross Wellington (pers. comm.) reports that as part of a development approval process, artificial green and golden bell frog habitat were designed and installed with draining features to allow removal of water and thus facilitate on-going eradication of gambusia.

Public education can be focussed on publicising the impacts on the environment and native frog and fish species and reporting the presence of gambusia. The objectives of the public education would be substantial reductions in translocations and re-introductions of gambusia and increased knowledge of the existing locations of gambusia.

# 9. Proposed Management of *Gambusia*

## 9.1 Introduction

History suggests that the eradication of introduced fish is often impractical and almost always unsuccessful (Kailola 1990). This is likely to be the case with gambusia in Australia, where it occupies long stretches of inter-connected waterways and many other types of habitats across most of its range, and for which effective and species-specific control measures are currently lacking. For this reason, an integrated, targeted management strategy is proposed in this threat abatement plan, which seeks to contain the spread of gambusia and, where feasible, ameliorate the impacts of predation on threatened frogs by:

- minimising further human dispersal of gambusia through implementing enhanced government regulation, public education and awareness campaigns
- removing gambusia, where practical, from areas occupied by key populations of priority frog species
- creating supplementary gambusia-free habitat, adjacent to gambusia-inhabited populations of priority frog species, in areas where gambusia removal is considered not practical
- collaborating with broader water reform processes that seek to rehabilitate aquatic ecosystems and
- informing land managers by undertaking research into the biology and ecology of gambusia, its impacts on frogs and the efficacy of proposed control measures

## 9.2 Threat Abatement Actions

The broad objective of this plan is to ameliorate the impact of gambusia on frogs, particularly threatened frogs. This will be achieved through implementation of the actions identified below. Proposed actions are focussed on threatened frog species most likely to be impacted by gambusia and are both landscape and local in scale. Management of gambusia will be integrated with other natural resource management programs. The overall key performance criteria of this plan will be the increased viability of populations of key threatened frog species impacted by gambusia.

**Objective 1: Minimise human dispersal of *gambusia***

Humans have historically been considered a major mechanism for the spread of gambusia. Management actions then should be directed at minimising the influence humans have over increasing the range of this species. This may be achieved through increased regulation and enhanced public awareness of the ecological consequences of releasing gambusia into the environment. It is acknowledged that the dispersal of gambusia through natural events such as flooding or other animals, eg birds is unlikely to be prevented and impossible to manage.

***Action 1: Propose gambusia for declaration as a noxious fish in NSW***

The NPWS will liaise with NSW Fisheries to evaluate options and implications for the listing of gambusia as a noxious fish under the *Fisheries Management Act 1994* (FM Act). A declaration of gambusia as noxious will prohibit the sale, possession and introduction of gambusia into any waters unless under the authority of a permit issued by NSW Fisheries. In addition, Fisheries Officers, under the FM Act will then have the power to seize, take possession of and destroy gambusia.

A noxious declaration will also raise the profile of gambusia as a process threatening frogs in NSW and should benefit native frog species and other species such as freshwater fish and macro-invertebrates, which are also adversely impacted upon by the species. Media coverage and other public awareness actions will be implemented to accompany the proposed declaration. This action will be initiated within the first year of the plan.

***Action 2: Develop and disseminate education and awareness material***

The purpose of this action is to target those groups that may be responsible for, or have some association with, the maintenance and dispersal of gambusia in the environment. Groups to be targeted include:

- councils
- ornamental fish suppliers, keepers of aquarium fish and reptiles such as freshwater turtles
- property owners with farm dams
- school children and the
- general public

NPWS will prepare and implement an education strategy that informs each target group about the poor record of gambusia as a mosquito control agent and the subsequent potential impacts of deliberately, or inadvertently dispersing gambusia into the environment. The strategy will also provide practical methods for landholders to restore frog habitat and where practical remove gambusia from a waterbody. Education and awareness resources for consideration include fact sheets, continued dissemination of diverse frog conservation information (such as the NPWS (2001a) ‘Helping Frogs Survive’ brochure), NPWS Internet displays and media interviews.

NPWS will seek to collaborate with existing frog recovery projects and link with other government department initiatives (including those identified in Action 8 below) and interest group programs, which can assist with raising awareness about gambusia. They include: DLWC, NSW Waterwatch and Bugwatch programs, Sydney Water Streamwatch program, NSW Fisheries, Department of Education Field Study Centres, Pet Industry Joint Advisory Council, Frog and Tadpole Society and the Australia New Guinea Fishes Association.

The dissemination of educational material will be focussed on areas containing priority frog species most likely to be impacted by gambusia (refer to Objective 2, Action 4).

### *Action 3: Prepare environmental assessment guidelines for consultants and consent authorities*

The NPWS will prepare advice to assist consultants, Councils and government agencies responsible for making an assessment or determination of the likelihood of a development or activity, which may result in the introduction of gambusia into an area occupied by threatened frogs or a change to existing interactions between gambusia and threatened frogs. This action is relevant to part (g) of the 'eight part test' (ie Section 95 of the EP&A Act) when deciding if a proposed development is likely to have a significant impact on the survival of threatened species, populations and ecological communities.

**Performance Criteria:** Within the first year of the commencement of this plan, options for declaring gambusia noxious in NSW will be evaluated. Education and awareness material will be prepared and disseminated in the first two years of the plan. Within five years of commencement of the plan, public awareness of the issue and measures to mitigate ongoing human dispersal will be known amongst the target groups listed in actions two and three.

### Objective 2: Reduce impacts of gambusia on threatened frog species at key sites

This component of the plan is directed at ameliorating the impacts of gambusia at the local scale. Actions are targeted at those threatened frogs, (ie green and golden bell frog (*L. aurea*), southern bell frog (*L. raniformis*), wallum froglet (*C. tinula*), olongurra frog (*L. olongburensis*) and the endangered population of tusked frog (*A. brevis*)) identified as being of high to medium risk of impact from gambusia. The yellow-spotted bell frog (*L. castanea*) has not been recorded since 1973 (NPWS 2001b). Actions for this species would be triggered when extant populations are located.

### *Action 4: Survey threatened frog habitats for gambusia*

Surveys for gambusia, within and adjacent to habitats of high and medium priority threatened frog species will be conducted. Information from these surveys will improve our knowledge of the local distribution of gambusia in these habitats, particularly areas that are currently gambusia-free. Education and awareness resources identified in Action 2 can then be targeted to these areas, in an effort to prevent further human dispersal of gambusia.

NPWS will coordinate these surveys and where possible undertake them in conjunction with surveys proposed in future recovery plans for these threatened frog species. The support of volunteers or other groups collecting similar survey data will also be utilised where available.

This action will be implemented within the first two years of the plan, with a follow up survey in year five.

***Action 5: Remove gambusia at key sites for high priority threatened species***

Total removal of gambusia from the environment is not feasible at this time. However, opportunities may exist to control gambusia at key sites for high priority threatened frog species.

Selection of sites containing key populations of these species will be made in consultation with the relevant NPWS recovery plan coordinator. Each site will then be assessed to ascertain the practicality of removing gambusia. Sites that may be suitable for this action are small, enclosed waterbodies or isolated pools such as farm dams or drying creek beds where the likelihood of permanent gambusia removal is high and where the potential impacts to non-target species from the control method(s) used are considered low.

A pilot case study for each species will then be implemented to gauge the efficacy of the control technique and evaluate the response of the target species. If the control program is considered successful it will then be expanded to other suitable sites. Permission will be sought from land holders and relevant approval authorities prior to implementing any control measure such as draining a waterbody or applying a chemical treatment.

NPWS will coordinate the implementation of this action.

***Action 6: Create gambusia-free supplementary habitat key sites for high priority threatened frog species***

At sites where the removal of gambusia is not considered practical, opportunities for the creation of supplementary frog breeding habitat will be evaluated. The intent of this action is to develop areas of gambusia-free habitat adjacent to existing gambusia-inhabited habitat in key population areas. Supplementary habitat may be ephemeral in nature or periodically drained to ensure it remains free from gambusia.

Identification of suitable sites will be made in consultation with the relevant recovery plan coordinator and will be undertaken in conjunction with the evaluation of sites for removal of gambusia.

NPWS will coordinate the implementation of this action.

***Action 7: Monitor the response of threatened frog species to the creation of gambusia-free habitat***

NPWS will establish a rigorous monitoring program to measure the response of key threatened frogs at sites where gambusia is removed and where supplementary gambusia-free habitat is created. NPWS will undertake this action on an ongoing annual basis following the implementation of Actions 5 and 6 above.

**Performance Criteria**

Within two years of commencement of the plan, the presence or absence of gambusia in 75% of all habitats for high and medium risk frog species will be determined. In addition, within the life of the plan, programmes for the removal of gambusia and the creation of supplementary habitat for high priority threatened frog species will be established. The response of threatened frogs to gambusia removal and supplementary habitat creation programmes will be measured at these sites and reported on at the completion of the plan.

**Objective 3: Integrate this threat abatement plan with other aquatic restoration programs**

Modified habitats are particularly susceptible to gambusia invasion and effective amelioration of the impacts of gambusia can only be achieved through the restoration of aquatic ecosystems at the landscape scale (see section 6.2). This threat abatement plan therefore needs to link with other broad-scale water reform processes that seek to address aspects of habitat disturbance favoured by gambusia such as river impoundment, declines in water quality, changes to natural discharge patterns, thermal regimes and bank and channel alterations.

***Action 8: Link this threat abatement plan to broad-scale water reform and river health programs***

Current government legislation and programs relevant to this action are described in Section 2 of the plan and include:

- *Water Management Act 2000*
- *Catchment Management Amendment Bill 2001 (not yet passed) and the Catchment Management Act 1989*
- *NSW Weirs Policy 1995*
- *The NSW Wetlands Management Policy 1996*

There is no statutory requirement for threat abatement plans prepared under the *TSC Act* to be incorporated in, or implemented through the various legislative instruments described above. However, the NPWS is represented on various committees committed to implementing water reform programs and will advocate the importance of restoring aquatic ecosystems for the purpose of reducing the impacts of gambusia on frog species. Copies of this threat abatement plan will be provided to all relevant government agencies and committees responsible for river health and aquatic restoration programs.

The NPWS will also seek to liaise with NSW Fisheries during the preparation of a future threat abatement plan for the listed key threatening process *Introduction of fish to fresh waters within a river catchment outside their natural range* as required by the FM Act.

**Performance Criteria:**

All relevant national and state government agencies and committees will receive copies of the plan in the first year of commencement. Contact with NPWS representatives participating on various water reform committees will be made and annual updates on the progress of the plan provided. Also information from these committees will be used to better implement this plan where possible.

**Objective 4: Increase knowledge of the general ecology of gambusia, its impact on native frog species and mechanisms for its control.**

Research is required to address gaps in the knowledge of the biology and ecology of gambusia, its impact on native species and the efficacy and impacts of proposed control measures. Information derived from these studies will assist in refining current management practices and/or develop new approaches to the control or removal of gambusia from the environment. Recommended areas of research are identified in the actions below. It is proposed that each of these actions be undertaken by, or in partnership with an academic institution or government research organisation eg NSW Fisheries.

***Action 9: Conduct investigations into factors limiting the establishment of gambusia in nature***

Proposed topics for research include:

- factors limiting the distribution and abundance of gambusia. Proposed studies would assess habitat preferences of gambusia to better understand factors, which influence their establishment and govern their rate of increase at a site
- comparing the distribution and abundance of gambusia in undisturbed and modified habitats to gain a better understanding of what habitat conditions influence their presence and
- identifying mechanisms of gambusia dispersal, to better understand how gambusia invades different habitats, particularly those likely to support frogs at risk from gambusia predation

***Action 10: Investigate the impacts of gambusia on frog species***

Evidence linking gambusia to declines in native and threatened frogs is currently inconclusive. Research is required to clarify the impacts of gambusia on frogs and to ascertain the role of gambusia in the decline of frog species assemblages in synergy with other processes that also threaten their survival eg frog chytrid fungus. This plan has identified a number of threatened and native frog species most susceptible to population level impacts from predation by gambusia (Appendix 3). Further research is also recommended into the palatability of frog eggs and tadpoles to gambusia, and the effectiveness of tadpole survival strategies in avoiding negative interactions with gambusia would also clarify the likely impact of gambusia predation on frog species.

***Action 11: Trial Rotenone as a gambusia control technique***

Rotenone has potential in certain circumstances to be an effective gambusia control agent (refer to section 8 of this plan). Trials will be undertaken to identify suitable dose levels and assess potential impacts to non-target species. Potential sites will be selected in consultation with the EPA and NSW Fisheries, and will be confined to small, enclosed waterbodies.

An application for a research permit for the trials will be made with the National Registration Authority once suitable sites have been identified.

***Action 12: Monitor ongoing research into the control of gambusia***

The NPWS threat abatement plan coordinator will monitor ongoing advances in approaches to the management of pest species that may, or are being adapted to the management of gambusia eg Murray Darling Basin Commission funding of CSIRO research into 'daughterless carp technology'.

**Performance Criteria:**

Throughout the life of this plan, NPWS will seek partnerships and encourage research into the ecology of gambusia, its impacts on frogs and the development and efficacy of potential gambusia control measures. Relevant research outcomes will be incorporated into management.

**Objective 5: Ensure effective implementation of the threat abatement plan**

Implementation of this plan will require ongoing statewide coordination.

***Action 13: Provide support for the implementation of this plan***

Successful implementation of this threat abatement plan will require ongoing coordination through continued liaison with threatened frog recovery program coordinators, consultation with stakeholders such as NSW Fisheries, EPA, Local Councils, DLWC and individual landowners. The threat abatement coordinator will be responsible for overall implementation of threat abatement actions and communication of results of the plan to land management agencies, landholders and the public.

**Performance Criteria:**

Each of the actions identified in the plan will be initiated by the threat abatement coordinator within the prescribed timeframes (assuming funds for implementation are available). Progress toward objectives assessed by the performance criteria will be reviewed and updated in year five of plan.

## 10. Economic and Social Impacts of the Plan

The total cost of implementing the plan is estimated to be approximately $220,000 over five years. A breakdown of costs per action per year is provided in Appendix 4. Expected costs are approximations, which may require revision once actions are initiated. Some costs, identified in the plan may be partly absorbed by other recovery plans for threatened frog species or met by funding programs such as the NSW Biodiversity Strategy and Commonwealth Government Natural Heritage Trust. Approximately half the projected costs are attributed to research actions. The estimated cost of these actions may also be substantially reduced through the acquisition of a funding grant eg ARC Linkage Grant. Other economic impacts associated with implementation of this plan are likely to be minimal.

The major social benefit of ameliorating the impact of predation by gambusia will be meeting the desire of many persons in the community to protect native frogs, particularly threatened species. Implementation of the actions proposed in the plan may also benefit other groups of native species such as fish and macro-invertebrates. No impact on Aboriginal heritage is expected. There are unlikely to be any significant animal welfare issues related to this plan. Chemical control trials will be undertaken with the appropriate environment assessment, animal care and ethics and other relevant approvals to minimise non-target impacts.

## 11. Review Date

This threat abatement plan is to be formally reviewed by the NPWS in consultation with NSW Fisheries within five years of commencement of the plan.

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**Personal Communications**

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# Appendix 1: NSW Scientific Committee Final Determination

The Scientific Committee, established by the Threatened Species Conservation Act, has made a Final Determination to list Predation by *Gambusia holbrooki* (Plague Minnow) as a KEY THREATENING PROCESS on Schedule 3 of the Act. Listing of Key Threatening Processes is provided for by Division 2 Part 2 of the Act.
The Scientific Committee has found that:

1. *Gambusia holbrooki* Girard, 1859 (previously known as *Gambusia affinis*) (Plague Minnow, also known as Mosquito Fish) is a small freshwater fish originally introduced into Australia in the 1920s. The fish was imported as an aquarium fish but some were released into creeks around Sydney, Melbourne and Brisbane.
2. During the Second World War a government sponsored campaign was initiated to spread *Gambusia holbrooki* into as many east coast waterways as possible, as a control agent for mosquitoes.
3. *Gambusia holbrooki* is an aggressive and voracious predator. Overseas research has documented its impact on fish, invertebrates and frogs. (Grubb, J.C. 1972. American Midland Naturalist *88*, 102-8; Hurlbert, S.H., Zedler, J. & Fairbanks, D. 1972. Science 175, 639-41)
4. Recent research has documented that *Gambusia holbrooki* preys upon eggs and tadpoles of the green and golden bell frog, *Litoria aurea* (Morgan, L.A. & Buttermer, W.A. 1996. *Australian Zoologist* 30, 143-149, White, A.W. & Pyke, G.H. 1998 unpublished manuscript submitted to *Australian Zoologist*).
5. Other studies have demonstrated that *Gambusia* also preys upon *Litoria dentata* (Morgan & Buttermer *op.cit*), *Litoria lesueuri* (White & Pyke, *op.cit*) and *Limnodynastes peronii* (Webb, C. & Joss, J. 1997. *Australian Zoologist 30*, 316-26).
6. Presence of *Gambusia holbrooki* has been linked to the decline of *Litoria aurea*, the New England Bell Frog *Litoria castanea*, Southern Bell Frog *Litoria raniformis*, and the Southern Tablelands Bell Frog (*Litoria sp.*)
7. Breeding by *Litoria aurea* is almost completely restricted to water bodies lacking *Gambusia holbrooki.*
8. In view of 3, 4, 5, 6 above the Scientific Committee is of the opinion that Predation by *Gambusia holbrooki* is a serious threat to the survival of *Litoria aurea* and *Litoria castanea*, both species listed as threatened under the Threatened Species Conservation Act, and to other species of frog, and that predation by *Gambusia holbrooki* is therefore eligible to be listed as a key threatening process because it adversely affects two or more threatened species and it could cause species that are not threatened to become threatened.

Exhibition period: 29/1/99 - 12/3/99

# Appendix 2: NSW rivers survey records of *Gambusia*

Rivers and their catchments where gambusia have been recorded during the NSW Rivers Survey 1994-1996 (Faragher and Lintermans 1997).

**Macquarie River Catchment**

Turon

Little

Talbragar

Macquarie

Bogan

Duckmaloi

Fish

**Namoi River Catchment**

MacDonald

Peel

Cockburn

**Hawkesbury River Catchment**

Cox's

Mangrove Creek

**Hunter River Catchment**

Hunter

Goulburn

**Macleay River Catchment**

Gara

Macleay

**Gwydir River Catchment**

Horton

Gwydir

**Shoalhaven River Catchment**

Shoalhaven

**Murrumbidgee River Catchment**

Yass

Colombo Creek

**Lachlan River Catchment**

Retreat

**Clarence River Catchment**

Clarence

Orara

**Richmond River Catchment**

Richmond

Leycester Creek

**Manning River Catchment**

Gloucester

# Appendix 3: Development of a rank scoring system to predict gambusia impact on native frog species

A model to rank the likelihood of population level impacts of gambusia predation on native frogs, including threatened species and endangered populations, has been prepared to guide management and better target threat abatement actions. Published scientific literature of the impacts of gambusia predation on frogs is relatively scarce, being predominantly restricted to a small number of species. However, it is acknowledged that frogs do possess ecological attributes that render them susceptible to predation and as a precaution, this plan advocates an adaptive approach to their management ie undertake some management intervention for those frogs species likely to have some population level impacts concurrent with ongoing research that seeks to clarify the existence and degree of impact.

The model for the likelihood of impact is defined as:

Sensitivity rating = (microhabitat score) x (dietary overlap + fecundity + exposure/protection of eggs + length of larval period + anti-predator avoidance)

This model gives particular emphasis to microhabitat (multiplicative factor), so that those stages of the frog life cycle (ie their eggs and tadpoles) which occur in inaccessible habitats or habitats unlikely to be invaded by gambusia score zero.

Threatened species comprise the first group of frogs in the accompanying table followed by the remaining native frog species.

**Frog Microhabitat Use**

This factor describes the accessibility of frog eggs and tadpoles to predation and/or interference competition from gambusia. Frog species, which breed in habitat unlikely to be accessed by gambusia score zero.

**0 -** Eggs and tadpoles occur in habitats inaccessible to gambusia. That is, where reproduction is totally terrestrial for all stages of the life cycle, or where the life cycle is partially aquatic but associated with water bodies unlikely to be colonised by gambusia (eg isolated ephemeral pools or high discharge first or second order streams).

**1 -** Eggs and tadpoles are partially aquatic with gambusia having potential to opportunistically occupy habitats such as billabongs, farm dams or ox-bows through flooding or human dispersal.

**1 -** Eggs and tadpoles are aquatic with a minimal chance of gambusia being present because they are not connected to permanent streams or waterbodies (eg ephemeral clay pans or sand dune swales etc).

**2 -** Eggs and tadpoles are aquatic and occur in slow or moderate discharge third and fourth order streams with a reasonable chance of gambusia being present, or

**2 –** Eggs and tadpoles are aquatic and are associated with a broad range of waterbody types, including flooded areas, permanent ponds and slow moving streams where there is a reasonable chance of gambusia being present in some of these habitats.

**3 -** Those frog species whose life cycle occurs predominantly in permanent ponds, lentic interconnecting pools or slow flowing low altitude streams which gambusia can easily access.

**Dietary Overlap**

This factor describes the potential impacts of gambusia on frog species (essentially their tadpole stage) which have similar dietary preferences. Competition for food may occur in areas where resources are limiting.

**0 -** None or minor overlap in diet ie tadpoles that are mostly herbivorous

**1 -** High overlap in diet ie tadpoles that are predominantly macro-invertebrate or insect feeders

**Fecundity**

This factor describes the potential for frog species with a higher intrinsic rate of increase to compensate for mortality from gambusia predation on eggs.

**0 –** High fecundity > 1000 eggs

**1 –** Moderate fecundity of 500 to 1000 eggs

**2 –** Low fecundity < 500 eggs

**Exposure/protection of eggs**

This factor describes the specific reproductive characteristics of frog spawn which place it at a higher risk of impact from predators. It assumes that frog species with foam egg masses are less vulnerable to predation than those with loose, simple egg masses.

**0 -** Terrestrial egg mass not accessible to gambusia

**1 -** Egg masses occur in aquatic habitat not easily accessible to gambusia eg in burrows, amongst litter, under rocks or on banks above water level.

**2 -** Species with foam egg masses in aquatic habitats accessible to gambusia

**3 -** Species with simple egg masses with loose eggs or clumps of eggs in exposed situations readily accessible to gambusia eg attached to submerged vegetation

**Length of larval period**

This factor describes the potential for frog species to be at higher risk of predation, if the aquatic stage of the life cycle occurs over a longer time frame.

**1 -** Egg and tadpole periods less than 3 months

**2 –** Egg and tadpole periods of approximately 3 months or greater

**Anti-predator adaptation**

This factor describes the potential for tadpoles to decrease the probability of predation through responses such as avoidance behaviour. Very little information is known on this factor, so scores are based on subjective opinion rather than known fact.

**0 –** behaviour possibly effective in decreasing risk of predation eg schooling of tadpoles, or avoidance actions such as hiding amongst vegetation

**1 –** no such behaviours currently known

| Scientific name | Common name | Microhabitat | Dietary Overlap | Fecundity | Exposure protection of eggs | Length of larval period | Anti-predator avoidance | Sensitivity Ranking |
|---|---|---|---|---|---|---|---|---|
| ***Endangered Frogs*** | | | | | | | | |
| *Litoria aurea* | Green and Golden Bell Frog | 3 | 1 | 0 | 3 | 1 | 1 | 18 |
| *Litoria castanea* | Yellow spotted Tree frog | 3 | 1 | 0 | 3 | 1 | 1 | 18 |
| *Litoria raniformis* | Southern Bell Frog | 3 | 1 | 0 | 3 | 1 | 1 | 18 |
| *Mixophyes iteratus* | Giant Barred Frog | 2 | 1 | 0 | 1 | 2 | 0 | 8 |
| *Litoria booroolongensis* | Booroolong Frog | 2 | 0 | 0 | 1 | 1 | 1 | 6 |
| *Neobatrachus pictus* | Painted Burrowing Frog | 1 | 0 | 1 | 3 | 1 | 1 | 6 |
| *Litoria spenceri* | Spotted Frog | 0 | 0 | 1 | 1 | 2 | 1 | 0 |
| *Mixophyes fleayi* | Fleay's Barred Frog | 0 | 1 | 2 | 1 | 2 | 1 | 0 |
| *Pseudophryne corroboree* | Southern Corroboree Frog | 0 | 1 | 2 | 0 | 2 | 1 | 0 |
| ***Endangered Populations*** | | | | | | | | |
| *Adelotus brevis* Nandewar and New England Bioregions | Tusked Frog | 2 | 1 | 2 | 1 | 2 | 0 | 14 |

| Scientific name | Common name | Microhabitat | Dietary Overlap | Fecundity | Exposure protection of eggs | Length of larval period | Anti-predator avoidance | Sensitivity Ranking |
|---|---|---|---|---|---|---|---|---|
| ***Vulnerable Frogs*** | | | | | | | | |
| *Crinia tinnula* | Wallum Froglet | 3 | 0 | 2 | 2 | 1 | 1 | 18 |
| *Litoria olongburensis* | Olongurra Frog | 2 | 1 | 1 | 3 | 1 | 0 | 12 |
| *Assa darlingtoni* | Pouched Frog | 0 | 0 | 2 | 0 | 1 | 1 | 0 |
| *Heleioporus australiacus* | Giant Burrowing Frog | 0 | 1 | 1 | 1 | 2 | 1 | 0 |
| *Litoria brevipalmata* | Green-thighed Frog | 0 | 0 | 2 | 3 | 1 | 1 | 0 |
| *Litoria littlejohni* | Littlejohn’s Tree Frog | 0 | 1 | 2 | 3 | 2 | 1 | 0 |
| *Litoria piperata* | Peppered Frog | 0 | 0 | 2 | 2 | 2 | 0 | 0 |
| *Litoria subglandulosa* | Glandular Frog | 0 | 0 | 2 | 2 | 2 | 0 | 0 |
| *Mixophyes balbus* | Stuttering Frog | 0 | 1 | 1 | 1 | 2 | 0 | 0 |
| *Philoria kundagungan* | Mountain Frog | 0 | 0 | 2 | 0 | 1 | 1 | 0 |
| *Philoria loveridgei* | Loveridge's Frog | 0 | 0 | 2 | 0 | 1 | 1 | 0 |
| *Philoria sphagnicola* | Sphagnum Frog | 0 | 0 | 2 | 0 | 1 | 1 | 0 |
| *Pseudophryne australis* | Red-crowned Toadlet | 0 | 0 | 2 | 0 | 2 | 1 | 0 |
| *Pseudophryne pengilleyi* | Northern Corroboree Frog | 0 | 0 | 2 | 0 | 2 | 1 | 0 |

| Scientific name | Common name | Microhabitat | Dietary Overlap | Fecundity | Exposure protection of eggs | Length of larval period | Anti-predator avoidance | Sensitivity Ranking |
|---|---|---|---|---|---|---|---|---|
| ***Other native species*** | | | | | | | | |
| *Litoria ewingii* | Brown Tree Frog | 3 | 1 | 1 | 3 | 2 | 1 | 24 |
| *Litoria fallax* | Eastern Dwarf tree Frog | 3 | 1 | 1 | 3 | 1 | 1 | 21 |
| *Litoria peronii* | Perons Tree Frog | 3 | 1 | 0 | 3 | 2 | 1 | 21 |
| *Litoria tyleri* | | 3 | 1 | 1 | 3 | 1 | 1 | 21 |
| *Litoria verreauxii* | | 3 | 1 | 1 | 3 | 1 | 0 | 18 |
| *Paracrinia haswelli* | Haswells Frog | 2 | 1 | 2 | 3 | 2 | 0 | 16 |
| *Litoria freycinetti* | Freycinet’s frog | 2 | 1 | 2 | 3 | 1 | 1 | 16 |
| *Limnodynastes dumerilii* | Eastern Banjo Frog | 3 | 1 | 0 | 2 | 2 | 0 | 15 |
| *Crinia parinsignifera* | | 2 | 0 | 2 | 3 | 1 | 1 | 14 |
| *Crinia signifera* | Common Eastern froglet | 2 | 0 | 2 | 3 | 1 | 1 | 14 |
| *Crinia sloanei* | | 2 | 0 | 2 | 3 | 1 | 1 | 14 |
| *Litoria gracilenta* | Dainty Green Tree Frog | 2 | 1 | 1 | 3 | 1 | 1 | 14 |
| *Litoria latopalmata* | | 2 | 1 | 1 | 3 | 1 | 1 | 14 |
| *Litoria pearsoniana* | | 2 | 0 | 2 | 2 | 2 | 1 | 14 |
| *Litoria jervisiensis* | Jervis Bay Tree | 2 | 1 | 1 | 3 | 1 | 1 | 14 |

| Scientific name | Common name | Microhabitat | Dietary Overlap | Fecundity | Exposure protection of eggs | Length of larval period | Anti-predator avoidance | Sensitivity Ranking |
|---|---|---|---|---|---|---|---|---|
| | Frog | | | | | | | |
| *Adelotus brevis* | Tusked Frog | 2 | 1 | 2 | 1 | 2 | 0 | 12 |
| *Mixopheyes fasciolatus* | Great Barred Frog | 3 | 1 | 0 | 1 | 2 | 0 | 12 |
| *Litoria nasuta* | Rocket Frog | 2 | 1 | 0 | 3 | 1 | 1 | 12 |
| *Litoria phyllochroa* | Leaf Green Tree Frog | 2 | 0 | 2 | 3 | 1 | 0 | 12 |
| *Litoria fletcheri* | Long-thumbed frog | 2 | 1 | 0 | 2 | 2 | 0 | 10 |
| *Litoria interioris* | Giant Banjo frog | 2 | 1 | 0 | 2 | 2 | 0 | 10 |
| *Litoria. peronii* | Brown-striped Frog | 2 | 1 | 0 | 2 | 2 | 0 | 10 |
| *Litoria salmini* | Salmon-striped Frog | 2 | 1 | 0 | 2 | 2 | 0 | 10 |
| *Litoria tasmaniensis* | Spotted grass Frog | 2 | 1 | 0 | 2 | 2 | 0 | 10 |
| *Litoria terraereginae* | Northern Banjo Frog | 2 | 1 | 0 | 2 | 2 | 0 | 10 |
| *Uperoleia fusca* | | 2 | 0 | 2 | 1 | 1 | 1 | 10 |
| *Uperoleia capitulata* | | 2 | 0 | 2 | 1 | 1 | 1 | 10 |
| *Uperoleia laevigata* | | 2 | 0 | 2 | 1 | 1 | 1 | 10 |
| *Uperoleia tyleri* | | 2 | 0 | 2 | 1 | 1 | 1 | 10 |

| **Scientific name** | **Common name** | **Microhabitat** | **Dietary Overlap** | **Fecundity** | **Exposure protection of eggs** | **Length of larval period** | **Anti-predator avoidance** | **Sensitivity Ranking** |
|---|---|---|---|---|---|---|---|---|
| *Uperoleia rugosa* | | 2 | 0 | 2 | 1 | 1 | 1 | 10 |
| *Litoria lesueuri* | Leseurs Frog | 3 | 1 | 0 | 1 | 1 | 0 | 9 |
| *Litoria ornatus* | Ornate Burrowing Frog | 2 | 1 | 0 | 2 | 1 | 0 | 8 |
| *Litoria citropa* | Blue Mountains Tree Frog | 2 | 0 | 0 | 3 | 1 | 0 | 8 |
| *Lechriodus fletcheri* | Fletchers frog | 1 | 1 | 2 | 1 | 1 | 1 | 7 |
| *Neobatrachus centralis* | Trilling Frog | 1 | 1 | 1 | 3 | 1 | 1 | 7 |
| *Neobatrachus sudelli* | | 1 | 1 | 1 | 3 | 1 | 1 | 7 |
| *Litoria rubella* | Desert Tree Frog | 1 | 1 | 1 | 3 | 1 | 1 | 7 |
| *Geocrinia victoriana* | | 1 | 0 | 2 | 1 | 2 | 1 | 6 |
| *Notaden bennettii* | Crucifix Toad | 1 | 0 | 1 | 3 | 1 | 1 | 6 |
| *Cyclorana verrucosa* | | 1 | 1 | 0 | 3 | 1 | 1 | 6 |
| *Cyclorana brevipes* | | 1 | 1 | 1 | 3 | 1 | 0 | 6 |
| *Cyclorana novaehollandiae* | | 1 | 1 | 1 | 3 | 1 | 0 | 6 |
| *Cyclorana alboguttata* | Striped Burrowing Frog | 1 | 1 | 0 | 3 | 1 | 1 | 6 |
| *Litoria caerulea* | Green Tree Frog | 1 | 1 | 0 | 3 | 1 | 1 | 6 |

| Scientific name | Common name | Microhabitat | Dietary Overlap | Fecundity | Exposure protection of eggs | Length of larval period | Anti-predator avoidance | Sensitivity Ranking |
|---|---|---|---|---|---|---|---|---|
| *Litoria chloris* | Red-eyed tree frog | 1 | 1 | 0 | 3 | 1 | 1 | 6 |
| *Cyclorana platycephala* | | 1 | 1 | 0 | 3 | 1 | 0 | 5 |
| *Crinia deserticola* | | 0 | 0 | 2 | 3 | 1 | 1 | 0 |
| *Pseudophryne bibronii* | Brown toadlet | 0 | 0 | 2 | 0 | 2 | 1 | 0 |
| *Pseudophryne coriacea* | Red-backed Toadlet | 0 | 0 | 2 | 0 | 2 | 1 | 0 |
| *Pseudophryne dendyi* | | 0 | 0 | 2 | 0 | 2 | 1 | 0 |
| *Litoria dentata* | Bleating Tree Frog | 0 | 1 | 0 | 3 | 1 | 0 | 0 |
| *Litoria revelata* | | 0 | 1 | 2 | 1 | 1 | 1 | 0 |

# Appendix 4: Threat abatement plan cost table

Estimated costs of implementing the actions identified in this threat abatement plan.

| Action No: | Action Title | Priority | Estimated Cost/yr | | | | | Total Cost | Responsible party/funding source | In-Kind Funds | Cash Funds |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Yr 1** | **Yr 2** | **Yr 3** | **Yr 4** | **Yr 5** | | | | |
| 1 | Proposal to declare gambusia as 'noxious' | 1 | $3500 | | | | | $3500 | NPWS | $3500 | |
| 2 | Develop education and awareness tools | 1 | $3500 | $7000 | $3500 | | | $14000 | NPWS | $7000 | $7000 |
| 3 | Provide environmental assessment advice | 1 | $700 | | | | | $700 | NPWS | $700 | |
| 4 | Survey for gambusia | 2 | $2000 | $3500 | | | $3500 | $9000 | NPWS | $9000 | |
| 5 | Undertake targeted control | 1 | | $6000 | $5000 | $5000 | | $16000 | NPWS | $10000 | $6000 |
| 6 | Create supplementary habitat | 1 | | | $6000 | $5000 | | $11000 | NPWS | $6000 | $5000 |
| 7 | Monitor response of threatened frogs to gambusia removal | 1 | | | $8000 | $8000 | $8000 | $24000 | NPWS | $15000 | $9000 |
| 8 | Encourage and participate in broad scale river health programs | 2 | $0 | $0 | $0 | $0 | $0 | $0 | NPWS | | |
| 9 | Investigate factors limiting dispersal of gambusia | 2 | | $17000 | $17000 | $17000 | | $51000 | NPWS, academic institution &/or other research institution | | $51,000 |
| 10 | Clarify impacts of gambusia on frogs | 2 | | $11000 | $7000 | $12000 | | $30000 | NPWS, academic institution &/or other research institution | | $30,000 |
| 11 | Undertake chemical control trials | 2 | | | $22000 | | | $22000 | NPWS, academic institution &/or other research institution | | $22,000 |
| 12 | Monitor progress of research | 2 | $0 | $0 | $0 | $0 | $0 | $0 | NPWS | | |
| 13 | Coordinate plan | 1 | $10500 | $10500 | $7000 | $7000 | $7000 | $42000 | NPWS | $42,000 | |
| Total | | | | | | | | $223,200 | | $93,200 | $130,000 |

Priority ratings are: 1- Action critical to meeting plan objectives, 2-Action contributing to meeting plan objectives. 'In-Kind' Funds represent salary component of permanent staff and current resources.
'Cash' Funds represent the salary component for temporary staff and other costs such as travel and the purchasing of equipment.
Recovery Plan Coordination includes all actions associated with 'in-kind' administration and general implementation of the recovery plan and is assumed to absorb costs associated with actions 8 and 12.