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GAMBUSIA HOLBROOKI PREDATION ON *PSEUDACRIS FERIARUM* TADPOLES

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***Abstract.*—Although introduced world-wide for mosquito control, the Eastern Mosquitofish (*Gambusia holbrooki*) is now a major predator of amphibian larvae where it has been introduced. Because few researchers have examined the effects of *Gambusia* predation on anurans with which it has co-evolved, I compared survival of Upland Chorus Frog (*Pseudacris feriarum*) tadpoles in the presence and absence of *G. holbrooki*. I added 40 hatchling tadpoles to 12 cattle tanks, six of which contained *Gambusia*. After two weeks I found no tadpoles in tanks containing *Gambusia*, but many tadpoles in all the fish-free tanks. These results indicate that *Gambusia* are highly effective predators on small anuran larvae, even on species that share a long co-evolutionary history.**

Key Words.—Eastern Mosquitofish; *Gambusia holbrooki*; predation; *Pseudacris feriarum*; tadpole; Upland Chorus Frog

INTRODUCTION

Introduced predators are one source of local amphibian declines and even extinctions (Stebbins and Cohen 1995; Hecnar and M'Closkey 1997; Kats and Ferrer 2003; Kiesecker 2003). In California, introduced larvae-eating fish have driven the Mountain Yellow-legged Frog (*Rana muscosa*) and the Red-legged Frog (*R. aurora draytonii*) from their optimal habitat (Bradford et al. 1993; Fisher and Shaffer 1996; Knapp and Matthews 2000). Introduced fish also negatively impacted the European Tree Frog (*Hyla arborea*) in Sweden (Brondmark and Edenhamn 1994). Members of the genus *Gambusia* have been especially problematic around the globe. Humans have introduced these "mosquitofish" for their purported ability to control numbers of mosquito larvae. However, researchers now know that introduced *Gambusia* eat more than just mosquito larvae (Miura et al. 1979; Bence 1988); amphibian larvae are clearly part of their diet (Webb and Joss 1997; Goodsell and Kats 1999; Lawler et al. 1999; Komak and Crossland 2000).

Researchers often assume that a lack of evolutionary contact with such predators is a primary reason these impacts are so devastating (Kats and Ferrer 2003). Many amphibians coexist naturally with the Eastern Mosquitofish (*Gambusia holbrooki*) in the southeastern United States. Consequently, researchers believe that such species have had the opportunity to evolve defensive mechanisms that allow for such coexistence (Kruse and Francis 1977; Petranka 1983). Yet few researchers have investigated the effects of *G. holbrooki* on amphibians in its native range (but see Grubb 1972; Baber and Babbit 2004). I used an experimental approach to assess the effects of the presence of *G. holbrooki* on the survivorship of young larvae of the Upland Chorus Frog (*Pseudacris feriarum*), a species that breeds in both ephemeral and more permanent waters (Moriarty and Lannoo 2005).

MATERIALS AND METHODS

In late August 2005, I filled each of 12 oval 100-gallon (378-l) cattle tanks with 375 l of water, approximately 0.5 kg pine needles, and 250 mg alfalfa pellets. I arranged the tanks in two rows (six pairs of tanks) inside a chain-link fence near the Davidson College greenhouse in Davidson, Mecklenburg County, North Carolina (lat 35.4888, long -80.8275). One week later I inoculated each tank with 1 l of pond water. In late November, I captured wild *G. holbrooki* from a wetland area on the Catawba College ecological preserve in Salisbury, Rowan County, North Carolina (lat 35.6921, long -80.4865), a location also known as a breeding site for *P. feriarum*. The same day, I added 20 *Gambusia* (all between 2 and 4 cm in length) to one tank in each of the six pairs of tanks. I created similar size distributions of *Gambusia* in each of the six tanks. On 15 February 2006, I added an upright 9-cm x 19-cm x 39.5-cm cement cinderblock to each tank. On each cinderblock I placed a white 28 cm diameter ceramic dinner plate approximately 10 cm under the surface of the water.

On 19 February 2006 I collected ready-to-hatch egg masses of *P. feriarum* from a site in Rowan County (lat 35.6711, long -80.5729) and brought them into the laboratory in Davidson. By 20 February 2006, most of the eggs had hatched. At 1300 on 20 February, I placed 40 hatchling tadpoles into 500 ml plastic containers floating in each of the 12 cattle tanks. On 20 February 2000, I released 40 temperature-acclimated tadpoles into each of the tanks. Because *Gambusia* are primarily diurnal (Barrier and Hicks 2006), I introduced the tadpoles to the tanks at night to minimize initial predation. All tanks possessed refugia (pine needles, algal growth) in which tadpoles could hide from fish. I conducted no water quality assessments. To assess survival of the tadpoles, I sampled each tank by counting the number of tadpoles visible on the white plate two weeks later, at 2000 on 5 March 2006. I compared the distribution of tadpoles in each pair of tanks using a Wilcoxon Signed-Rank test (two-tailed, $\alpha = 0.05$).

RESULTS

The presence of *Gambusia* had a clear effect on the survivorship of *P. feriarum* tadpoles ($W = 10.5$, $df = 5$, $P = 0.031$). In all the tanks without *Gambusia*, I observed at least two tadpoles on the submerged plate; I observed no tadpoles on the plates in the tanks containing *Gambusi*a (Table 1). Moreover, close inspection of the walls and bottoms of the tanks revealed numerous additional tadpoles in the tanks without *Gambusia*; I detected no tadpoles in any of the tanks containing *Gambusia*. In subsequent weeks, I never observed tadpoles in any tanks with fish and always observed tadpoles in fish-free tanks.

DISCUSSION

The most parsimonious explanation for the disappearance of tadpoles from tanks containing *Gambusia* is that the fish devoured most, if not all, of the tadpoles very quickly. Although I cannot rule out the possibility that the tadpoles engaged in cannibalism (see McDiarmid and Altig 1999; McCallum and Trauth 2001), *Gambusia* predation presumably explains the dramatic difference between fish-free and fish-filled tanks. This finding corresponds with recent research regarding the predatory effects of *Gambusia*. Many reports of predation of Australian tadpoles by introduced *Gambusia* exist (Morgan and Buttermer 1996; Komak and Crossland 2000; Hamer et al. 2002). Moreover, there is now experimental evidence detailing the precise nature of these negative impacts: Gamradt and Kats (1996) documented decreased survivorship of larval California Newts (*Taricha torosa*) in the presence of Western Mosquitofish (*G. affinis*). Goodsell and Kats (1999) found similar decreases in survivorship of larval Pacific Tree Frogs (*Hyla regilla*). Lawler et al. (1999) found that *G. affinis* had multiple negative effects on California Red-legged Frog (*Rana aurora*) tadpoles: increased rates of tail injury, reduced metamorph size, decreased activity levels, and reduced rates of metamorphosis.

Multiple factors may influence the severity of *Gambusia* predation on anuran tadpoles, including the nutritional status of the *Gambusia* (Webb and Joss 1997; Pyke and White 2000), the movement of the tadpoles (Pyke and White 2000), and tadpole size (Webb and Joss 1997). Interestingly, Pyke and White (2000) also found that the availability of some cover (rocks) did not protect Green and Golden Bell Frogs (*Litoria aurea*) from attack. Similarly, Baber and Babbit (2004) found that even in the presence of abundant cover, *Gambusia* were very effective at eating tadpoles of *Hyla squirella* and *Gastrophryne carolinensis*, both species which have an evolutionary history with *Gambusia*. Although I did not feed the *Gambusia* in my experiment regularly, they lived at relatively low densities and had access to the aquatic invertebrates within the tanks. Moreover, the presence of *Gambusia* in the tanks corresponded with winter, when the metabolic rate (and nutritional requirements) of the fish were minimal. Nevertheless, my results echo those of Baber and Babbit (2004) in demonstrating that the efficiency of *Gambusia* as predators of anuran larvae is not limited to situations in which *Gambusia* are new to the community.

This is not to say that *G. holbrooki* has not acted as a selective pressure on *P. feriarum*. For example, adult *P. feriarum* tend not to breed in permanent bodies of water (Skelly 1996), where the danger from predators is highest. *Pseudacris feriarum* tadpoles also alter their behavior in the presence of predators (Skelly 1996). For example, Bridges (2002) showed that *P. feriarum* swam less and used refuges more in the presence of Eastern Newts (*Notopthalmus viridescens*). However, despite a long period of coexistence in southeastern North America, any defenses that *P. feriarum* has evolved

TABLE 1. Relative survival of *Pseudacris feriarum* in 378-l cattle tanks with and without *Gambusia holbrooki*.

Tank Set	Tank	Initial Contents (20 Feb)	Tadpoles Observed (5 Mar)
1	A	20 fish, 40 tadpoles	0
	B	40 tadpoles	4
2	A	40 tadpoles	2
	B	20 fish, 40 tadpoles	0
3	A	20 fish, 40 tadpoles	0
	B	40 tadpoles	5
4	A	40 tadpoles	5
	B	20 fish, 40 tadpoles	0
5	A	20 fish, 40 tadpoles	0
	B	40 tadpoles	6
6	A	40 tadpoles	2
	B	20 fish, 40 tadpoles	0

specifically against *G. holbrooki* appear not to be particularly effective, at least at the early tadpole stage.

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