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Conservation biology

Biodiversity and ecosystem risks arising from using guppies to control mosquitoes

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Deploying mosquito predators such as the guppy (*Poecilia reticulata*) into bodies of water where mosquitoes breed is a common strategy for limiting the spread of disease-carrying mosquitoes. Here, we draw on studies from epidemiology, conservation, ecology and evolution to show that the evidence for the effectiveness of guppies in controlling mosquitoes is weak, that the chances of accidental guppy introduction into local ecosystems are large, and that guppies can easily establish populations and damage these aquatic ecosystems. We highlight several knowledge and implementation gaps, and urge that this approach is either abandoned in favour of more effective strategies or that it is used much more rigorously. Controlling mosquitoes does not need to come at the expense of freshwater biodiversity.

1. Introduction

Mosquito-borne illnesses are a significant health problem in many nations, and recent reports suggest that Zika and dengue are spreading [1–3]. Currently, there are no vaccines for these diseases; prevention focuses on lowering the chance of being bitten by a carrier mosquito [4]. One common prevention strategy is to deploy larvicidal predators in water bodies where mosquitoes breed. By feeding on mosquito larvae or eggs, these predators should reduce populations of infected mosquitoes. Fish were widely used for this purpose by British colonists in the early twentieth century [5], and continue to be included in public health guidelines [4,6]. In recent years, guppies (*Poecilia reticulata*) have been used on a large scale to fight dengue and Zika epidemics. In 2013, guppies were introduced into local water bodies as part of an effort to control a dengue epidemic in Pakistan [7], and in 2015–2016 guppies were introduced in city ponds, water tanks, and ditches to limit the spread of Zika and dengue in Brazil [8–10]. There are also news reports of citizens independently releasing guppies in disease-affected nations [11], and it is unlikely these deployments have expert oversight. A Google search of 'guppies and Zika' or 'guppies and dengue' results in hundreds of entries from newspapers and social media outlets, including 'how to' or 'do it yourself' websites. We provide four reasons why using guppies to control mosquitoes is an ineffective strategy that is dangerous to local biodiversity.

2. Experimental evidence that guppies control mosquitoes is inconsistent and problematic

Laboratory studies that feed mosquitoes to guppies ad libitum generally conclude that guppies are an effective predator because they consume mosquito larvae

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[12–14]. However, it is likely that these relatively simple experiments, which starve guppies beforehand, and only offer them mosquitoes to eat, overestimate the effectiveness of guppies as mosquito predators. Laboratory experiments using multiple prey species conclude that guppies prefer other prey over mosquitoes, particularly chironomids [15]. Faecal analysis from wild guppies suggests a much lower average mosquito feeding rate than in laboratory experiments [13,16]. In Trinidad, we have observed extensive feeding on mosquitoes when guppies are housed in planters full of stagnant water [17], but not in moving waters or in natural populations [18,19]. Guppies also eat fewer mosquitoes in polluted water, probably because they have a greater diversity of food choices [20].

Ideally, the efficacy of guppies in controlling mosquitoes should be tested using a meta-analysis on the existing literature, but it is difficult to achieve consensus because guppy–mosquito experiments vary widely in methodology (e.g. acclimation or starvation time prior to trial, aquarium size and vegetative cover) [12,21]. Many early studies do not use proper experimental design or statistics, and many community-wide tests do not report sufficient pre-treatment data [22]. Because of such limitations, a recent systematic review on the topic included only 13 out of approximately 5000 studies; it concluded that although fish reduce the density of larval *Aedes* spp. (mosquitoes that spread dengue and Zika) in water containers, it was difficult to link fish to a reduction in adult *Aedes* or to a decline in disease transmission [22]. More rigorous studies are needed to confirm that guppies are effective mosquito predators.

3. Chances of guppy escape and introduction into local ecosystems are unknown, but likely high

Although some official guidelines explicitly recommend using native fish fauna whenever possible [4], or mention that guppy escape can harm local fauna [6], they do not provide explicit guidelines for preventing guppy escape and subsequent introduction into local ecosystems. News reports from Pakistan, Colombia, Brazil and India suggest that guppies have been deployed in open water bodies (ditches, ponds and sewers) [7,23,24]. The risk of accidental guppy escape from such systems is high because flooding, humans or predators (e.g. birds) can transport these fish between water bodies. However, because these deployments are not monitored, we currently do not know the probability or extent of accidental guppy escape.

4. Guppies are excellent invaders

Unfortunately, some of the traits that make guppies attractive for mosquito control also make them potent invaders. Guppies reproduce frequently, give birth to live young and grow quickly [25]. Females have a short gestation time (approx. 28 days), and can store sperm for long periods after copulation; they are almost always pregnant when collected from natural populations [26]. A single, pregnant female guppy has a more than 80% chance of establishing a population when introduced to a new environment [5]. Guppies are highly plastic and can acclimate and evolve quickly in new environments [27,28]. They tolerate a wide range of environmental conditions (pollution, heat, turbidity, presence or absence of predators) [29–32], and can live in rivers, lakes, ponds, ditches and sewers [25].

5. Guppies deplete native fauna and alter ecosystems

Poecilia reticulata has a small native range in the Caribbean and the northern tip of South America, but has invaded ecosystems worldwide [5,25]. Approximately 40% of these invasions are attributed to past efforts to combat mosquitoes [5]. Guppies have dramatically changed invaded ecosystems within and beyond their native range. Guppy introductions into guppy-free habitats in Trinidad decrease resident fish density [33], and cause resident fish to mature earlier, increase their growth rates and their reproductive investment [34,35]. Guppies become the dominant fish species in introduction sites [34]. They disrupt these ecosystems by increasing primary productivity, recycled nitrogen, and nitrogen fluxes to grazers and filter feeders, while reducing nitrogen fluxes to collector–gatherers [36,37]. In Hawaii, guppies and other invasive poeciliids have reached densities 10–30× greater than native fish since their introduction in the 1920s to fight mosquitoes [38,39]. They have halved native goby densities and reduced their fitness [40,41]. Guppies have increased available dissolved nitrogen by up to eight fold, and have promoted the expansion of non-native invertebrates [38]. The vast majority of studies on the effects of invasive guppies are from low diversity ecosystems (e.g. Caribbean and Pacific islands); more studies are therefore needed from areas with high biodiversity. The effects of guppies on native fish and aquatic environments in Brazil are poorly studied, but invasive guppies may pose risks to Brazilian biodiversity [42].

6. Conclusion and recommendations

In our opinion, using guppies to control mosquitoes on a large scale is likely to be ineffective, and to have significant risks for local ecosystems and biodiversity. It is understandable that in times of epidemics governments need to act quickly and deploy as many disease-control methods as possible, but the time and expense of deploying fish can be directed towards more effective strategies (e.g. installing window screening [43]). At the very least, this practice should be controlled and monitored rigorously. Here, we have focused on guppies because they have been extensively used in recent epidemics; other mosquito-control fishes such as *Gambusia* spp. (aka. mosquitofish) can also cause negative ecological effects [44]. A central challenge is that studies examining using guppies to control mosquitoes are in the realm of medical and health science, and are separated from the wealth of knowledge on the ecology and evolution of the guppy. Furthermore, there exists an exhaustive body of ecological literature on biological control of a wide range of pests and diseases that can help inform best practices; recent efforts to integrate biological control with conservation practices are particularly useful [45]. We urge health and conservation arms of government to collaborate on implementing biological control of mosquitoes. It is important to recognize that even in environments where guppies are common or have already invaded (e.g. Trinidad, Hawaii and Brazil), many aquatic environments are guppy-free and contain native fauna that are sensitive to invasion and therefore need protection. Controlling mosquitoes need not come at the expense of freshwater biodiversity, which is already highly threatened in many tropical areas.

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