Review Article

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Biological control of mosquito populations through frogs: Opportunities & constrains

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The use of frogs and tadpoles for disease vector control is still largely unexplored. Frogs are an important part of the ecosystem with a role for insect and pest control including mosquitoes. Available information suggests the existence of many direct and indirect factors affecting the growth and survival of both prey and predators. Other controphic species that have influence on this relationship also show considerable effect. Still, the associations of different prey and predator relationships in the environment to assess the feasibility of use of a species as biocontrol agent for vector control and management. However, frogs cannot be used as an independent intervention for disease vector control and more research is needed to use them effectively for mosquito control.

Key words Frog - mosquito - tadpole - vector control

A debate is in India on the use of frogs for the control of mosquito larvae in view of decline of frog population and possible increase in mosquito density. Ban on killing frogs is already in effect in India[1] since 1972. The concern on the export of frog legs has also supported the ban on killing of frogs[2]. There is a strong perception that the decline in amphibians leads to an increase in mosquito population[3] which needs sufficient scientific evidence. Studies on the role of frogs in controlling mosquitoes are meagre thus, information on their effectiveness for mosquito control is lacking. In this review we discuss the reports and available information from various studies undertaken on the feasibility of use of frogs in mosquito control.

Frogs belong to the order Anura (tailess). They have evolved 250 million years ago and well adapted to varied ecology[4]. Order Anura comprises 5362 species from 45 families of which 237 species from 12 families are found in India[5]. All members of order Anura are frogs, while the members of the family *Bufonidae* are termed as “true toads”. Frogs have worldwide distribution except in Antarctica and some Oceanic Islands and live in diverse habitats, with wide diversity in tropical rainforests[4]. Frogs mainly breathe through skin making them sensitive to environmental changes including human actions that has resulted in their rapid reduction and disappearance[6-10] in many parts of the world. Habitat loss is a significant cause for the decline in frog population[11]. Globally frog population has declined dramatically since 1950s and more than 120 species are reported to be extinct since 1980s[12].

Complete metamorphosis from tadpole to adult frog occurs in 2-11 months depending on the physical condition and nutrition[4]. Frogs spend their entire life in and around the aquatic habitats or under moist leaves, rocks or logs. Most species of tadpoles are omnivorous and feed on microorganisms, algae, protozoans, larvae of insects, shrimps, eggs and young ones of amphibians. Almost all species of adult frogs are carnivores and consume invertebrates such as annelids, gastropods and arthropods including mosquitoes. A few may prey on vertebrates like fish, smaller frogs and smaller mammals. Studies have shown that 50 frogs can keep an acre of a rice paddy field free of insects[13]. Thus, frogs can keep a check on insect populations including mosquitoes.

Few genera of mosquitoes are major vectors of human diseases such as malaria, filariasis and viral diseases like Japanese encephalitis, dengue, dengue haemorrhagic fever, yellow fever, chikungunya, *etc*. Mosquitoes breed in varied habitats such as ponds, marshes, ditches, pools, drains, water containers and other similar water collections[14]. Different genera have shown specific breeding preferences. *Anopheles* sp. are associated with fresh water habitats whereas *Culex* sp. and *Mansonia* sp. may also be found in polluted conditions, including septic tanks and *Aedes* breeds in domestic, peri-domestic and other small water collection including desert coolers[14,15]. Frogs introduced into segregated mosquito larval breeding habitats such as ponds, puddles, tanks, *etc*., may prey on larvae and subsequently reduce vector population and vector borne disease burden[16]. On the other hand, selective removal of predators in the habitat by the use of pesticides[17] or other means might possibly lead to increase in vector populations and disease burden.

Studies on different predators like birds, mammals, amphibians, reptiles and other insect predators are scanty[18]. Insect predators like dragonfly larvae and aquatic beetles may feed on mosquito larvae but are not very effective in controlling their density[19]. Many cyclopoid copepods have been found to prefer mosquito larvae and to a range of other prey[20, 21]. Use of cyclopoid copepods as biocontrol agents have yielded rates factory results for the control of dengue vectors[19-23]. Tadpoles co-occur in a range of habitats with mosquito larvae[24]. Tadpoles consume mosquito larvae while frogs can reduce mosquito population by preying on adult mosquitoes. Studies on predation efficacy of four Australian tadpoles was very low and was stated to be not an useful biological control agent[25]. However, many studies have stated that mosquitoes are not the only preferred prey for frogs. Goodsell and Kats[26] working on breeding association of *Gambusia* (mosquito fish), Pacific-tree frog tadpoles and mosquito larvae have indicated negative effect on the breeding of tree frog in streams. This is stated that regardless of the relative abundance of larval mosquito, *Gambusia* fish shows preference for the tadpoles. Predation by tadpoles have been recorded to alter over all community structure in temporary ponds[27].

In a study by Komak and Crossland[28] on association of mosquito fish and *Limnodynastes omatus* (native frog) and *Bufo marinus* (non-native frog) it was stated that introduction of mosquito fish, *Gambusia affinis holbrooki* as a predator of eggs, hatchling and tadpoles affects both the native and non-native anurans thereby affecting the natural control of mosquito larvae. It may be noted that introduction of mosquito fish that preferably utilize amphibian eggs and tadpoles may cause substantial decline of amphibian populations. Blaustein and Margalit[29] tested the experimental interaction of mosquito larvae, *Culiseta longiarolata* and immatures of *Bufo viridis* which largely feed on periphyton may create competition for natural food. Further, it was also found that presence of *Bufo* tadpoles affect the growth of *Culiseta* and *vice versa* due to inter-specific competition not affecting survival of each other. They have also stated that *Culiseta* larvae preyed on *Bufo* hatchlings both in field and laboratory experiments affecting the *Bufo* population. In the light of these experiments it was cautioned to be careful while assigning prey-predator relationships based on available documented information alone. Mokany and Shine[30] conducted laboratory studies on association of mosquito larvae and tadpoles and reported negative effect on each other's development and survival, which was contemplated to be due to certain chemical and microbiological cues. Hagman and Shine[3] observed reduction in survival rates of mosquito larvae in the presence of *Bufo marinus* in the laboratory while in field a reduction in oviposition rates of mosquito was observed. The above studies on inter- and intra-specific association of mosquito larvae with frogs have stated that frogs cannot be discounted for use as predators of larvae but at the same time cannot be considered as a sole intervention for mosquito control. Studies have shown that tadpoles were reported to prey on mosquito larvae where they are the only food resource. Marian *et al*[31] reported that the tadpoles of *Rana tigrina* show a preference for pupal stages whereas other mosquito predators prefer early larval stages. Therefore, concurrent presence of other larvivorous organism might exert simultaneous predation pressure on different stages of mosquito immatures, which will be a more effective control measure. Many larvae escape from predation and metamorphose to pupal stages, in that case presence of tadpoles of *R. tigrina* will exert simultaneous pressure on pupal stages. Spielman and Sullivan[32] in their studies with *Hyla septentrionalis* and *Cx. pipiens* larvae reported that tadpoles preyed specifically on mosquito larvae and contemplated that the observed reduction of *Cx. pipens* population co-occurring with *Hyla* sp. in field may also be due to such specific prey preference. Kumar and Hwang[20] stated that tadpoles can rarely be accommodated in small container breeding habitats.

Ecological studies on consequences of interactions between the mosquito larvae and other controphic species are very few. Blaustein and Chase[33] stated that such controphic associations are likely to reduce the mosquito populations and thus could be an effective management tool for their control. They discussed the impact of controphic species on mosquitoes in a variety of direct and indirect ways with examples. Controphic species, some zooplanktons and tadpoles strongly and negatively affect the control of mosquito larvae by consuming the pathogenic bacteria that kill the mosquito larvae. Controphic species may also act as mutualists by serving as alternative prey and reduce the predation intensity on mosquitoes. Apparent competition occurs when tadpoles and mosquito larvae have common predator such as fish that prefer to prey on tadpoles. In this situation it could be hypothesized that frogs by presenting itself as an additional food source may allow the abundance of the fish. Later, with the imbalance in tadpole population, fish prey on mosquito larvae which are now abundant, resulting in possible reduction in mosquito larval density. Apart from all the various factors discussed it is also important to assess the preference of the predator as to size, mobility, density, ease of availability, synchrony of breeding of the prey[24]. Thus, the basic principle of community ecology of mosquito and their interaction with resources, predators, pathogens and controphic species is important to understand the prey-predator relationships in the environment. Role of controphic species as an important component in affecting mosquitoes remain largely unexplored.

Invasion of species has shown to disrupt the functioning of important components of a natural system. Hagman and Shine[3] stating various consequences of invasion of non-native, South American cane toads reported that it could reduce the survival rates, body size, oviposition preference of mosquitoes and negative association owing to its effect on native species. Therefore, careful analysis of the impact on ecosystem is necessary before selecting any organism for vector control especially with invasive species. Kumar and Hwang[20] stated that establishment of biocontrol agents needs a thorough understanding of their interactions with the co-occurring prey-predator community. In the environment, if the predator shows negative consumptive effect, it will reduce inter- and intra- specific competition thereby resulting in increased numbers of target species. Hence, overall evaluation of the impact of such introduction of frogs or other predators should be considered for possible benefits to human health. The knowledge from studies on the interaction of frog population with prey and predators can be applied to predict and manipulate its success for its use in vector control. Ecological theories of biomanipulation may be applied for such vector control programme management strategies.

Studies on the use of frog for mosquito control in India are very few. However, whether the decline of amphibians would result in increase in disease prevalence needs sufficient scientific evidence. Ecological investigations may provide insights for future research and should incorporate studies on the interactions, associations and prey-predator relationships between frogs, mosquitoes and other controphic species. Thus, there is a need to generate quantitative evidence to ascertain the possible role of frogs for disease vector control and management.

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