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SCIENTIFIC NOTES

PREDATION OF AQUATIC STAGES OF *ANOPHELES GAMBIAE* BY THE LOUISIANA RED SWAMP CRAWFISH (*PROCAMBARUS CLARKII*)

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ABSTRACT. Laboratory experiments lasting 1–3 days were conducted in 10-liter glass aquaria to evaluate the ability of the Louisiana red swamp crawfish (*Procambarus clarkii* [Decapoda: Cambaridae]) to consume the aquatic forms of mosquitoes. With *Anopheles gambiae* as the target species, significantly fewer mosquito larvae or pupae survived in the presence of either juvenile or adult crawfish, relative to conditions without crawfish, regardless of whether crawfish had alternative food or not. When alternative food was excluded, juvenile and adult crawfish had a comparable ability to consume mosquito larvae. However, when alternative food was available, adult crawfish consumed significantly fewer mosquito larvae than did juveniles. In the case of pupae, juvenile crawfish consumed significantly more mosquito pupae than did the adults when alternative food was excluded. No significant difference, relative to controls, was found in the proportion of mosquito pupae surviving when adult crawfish had alternative food. Results of the present study show that *P. clarkii* has the ability to consume the aquatic forms of anopheline mosquitoes and, therefore, may have an impact on populations of pathogen-transmitting mosquitoes in an area of Kenya where the crawfish has become common.

KEY WORDS Mosquito biocontrol, mosquito larvae, mosquito pupae, decapod crustaceans

Although insecticides continue to play a significant role in the control of mosquitoes involved in disease transmission, biological mosquito control with predatory organisms in most instances is more acceptable from an environmental standpoint and has been applied in many situations with reasonable success (World Health Organization 1995). Biological control with indigenous predators/parasites may be more available, comparatively less expensive, and more compatible with the economic realities of many countries of sub-Saharan Africa. Predatory organisms are particularly suitable for control of aquatic stages of mosquitoes. Among the organisms most extensively studied in this regard are larvivorous fish (El-Safi et al. 1985, Nelson and Keenan 1992, Fletcher et al. 1993, Victor et al. 1994). Studies on the potential of other freshwater organisms in biological control of immature forms of mosquitoes, however, are relatively few. Certain freshwater crustaceans are known to be capable of consuming aquatic forms of mosquitoes (Kay et al. 1992) or controlling macrophytes associated with aquatic habitats of mosquitoes (Feminella and Resh 1986). Thus, crustaceans were thought to be worthy of investigation for their potential as biological control agents of medically important mosquitoes in sub-Saharan Africa.

The present study was undertaken to determine the ability of the Louisiana red swamp crawfish (*Procambarus clarkii* (Girard) [Decapoda: Cambaridae]) to consume larvae and pupae of the anopheline mosquito *Anopheles gambiae* (Giles), an important transmitter of malaria and lymphatic filariasis in eastern Africa. Previous studies on the ability of crawfish to control schistosome-transmitting snails in Kenya (Hofkin et al. 1991a, 1991b; Mkoji et al. 1992) provided the impetus to conduct this study. Although *P. clarkii* is indigenous to the southern United States and northern Mexico, it has been introduced into several African countries, namely, Kenya, Uganda, Sudan, Zambia, Zimbabwe, and South Africa (Hobbs et al. 1989). In Kenya *P. clarkii* is widespread and currently occupies all the major drainage systems of the country (Lowery and Mendes 1977, Loker et al. 1992).

Fourth-instar larvae or newly molted pupae of the pink eye strain of *An. gambiae* were used in these studies. This strain was originally provided by Dr. Frank H. Collins, Department of Biological Sciences, University of Notre Dame, Notre Dame, IN, and has been maintained in continuous culture at the Kenya Medical Research Institute (KEMRI) since 1989. The crawfish used were collected from a reservoir in Nairobi with meat-baited crawfish traps. Juvenile crawfish (carapace length 10–20 mm) or adult crawfish (carapace length 30–40 mm) were used in experiments conducted in 10-liter glass aquaria containing aerated tap water at room temperature and a depth of 10 cm. A single crawfish was introduced into an aquarium containing 10 larvae or 10 pupae, plus or minus fresh lettuce leaves as alternative food for the crawfish. A previous study showed that crawfish readily consumed fresh lettuce leaves under laboratory conditions (Hofkin et al. 1992). No food was provided for the mosquito larvae, and crawfish were excluded from

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Table 1. Predation of larval and pupal *Anopheles gambiae* by the crawfish *Procambarus clarkii* under laboratory conditions.

Prey stage	Predator stage	Alternative food[1]	% prey survival (mean ± SD)[2] Experimentals with predators	% prey survival (mean ± SD)[2] Controls without predators
Larva	Juvenile	+	5.8 ± 6.7	90.8 ± 10.8
		−	15.0 ± 12.4	83.3 ± 16.7
	Adult	+	25.8 ± 7.9	80.0 ± 15.9
		−	14.2 ± 13.1	85.0 ± 13.1
Pupa	Juvenile	+	ND	ND
		−	16.7 ± 19.7	90.0 ± 10.4
	Adult	+	50.8 ± 26.8	83.3 ± 16.1
		−	40.4 ± 28.2	89.2 ± 17.9

[1] + = alternative food present, − = alternative food absent.
[2] Means (±SD) were calculated from results of 12 replicates. ND denotes experiment not done.

control aquaria. Each experiment was replicated 12 times. Experiments were scored 3 days after initiation of observations in the case of larvae or 1 day after the observations had begun for pupae. The percentages of larvae or pupae surviving at the end of the observation periods were calculated for each experiment, and the results were expressed as mean percentage (± SD) of larvae or pupae surviving. Statistical comparisons were made by the Mann–Whitney test, and P-values less than 0.05 were considered statistically significant.

The results of this study are summarized in Table 1. On average, >80% of mosquito larvae survived through 3 days in the absence of crawfish. For pupae, <50% were still present in control aquaria after 2 days, simply because many of them had already emerged as adults. Our results with pupae are therefore based on 24-h observations. No significant sex-related difference was observed in the ability of crawfish to consume mosquito larvae or pupae. Therefore, the data obtained with male or female crawfish were pooled in the analysis. Three days after introduction of crawfish into the aquaria, significantly fewer mosquito larvae were observed in the presence of either juvenile or adult crawfish relative to controls ($P < 0.001$). This was observed whether or not crawfish had alternative food. On several occasions, we observed crawfish capturing and consuming live mosquito larvae in the aquaria. We therefore attribute the disappearance of larval mosquitoes from aquaria containing crawfish to direct predation by crawfish. In the absence of alternative food, juvenile and adult crawfish showed comparable ability to consume mosquito larvae. However, adult crawfish consumed significantly fewer larvae than did juvenile crawfish when they were offered alternative food ($P < 0.01$). Juvenile crawfish seemed to prefer larval mosquitoes even when lettuce leaves were available as alternative food. Similar results were obtained when the pupae of *An. gambiae* were used as targets for crawfish. Significantly fewer mosquito pupae were observed in the aquaria containing crawfish relative to controls without crawfish ($P < 0.001$). In the absence of alternative food, juvenile crawfish consumed a greater proportion of mosquito pupae than did the adult crawfish (Table 1). The survival of pupae in the presence of adult crawfish, however, did not increase significantly when crawfish were provided with alternative food ($P > 0.05$).

The present study demonstrated that *P. clarkii* has the ability to consume aquatic forms of *An. gambiae*. Overall, juvenile crawfish had a greater ability to consume immature forms of mosquitoes than did adult crawfish, regardless of whether or not lettuce leaves were available as alternative food for crawfish. This observation was not totally unexpected. With age, the importance of vegetation and detritus in the diet increases (Goddard 1988). Even though we attribute the disappearance of the aquatic forms of mosquitoes from the aquaria containing crawfish to direct predation, we do not rule out a possible role of other crawfish-associated effects or mechanisms in the disappearance of these larval mosquitoes.

Because of the transient nature and small size of the majority of *An. gambiae* larval sites, natural interaction with *P. clarkii* is probably unlikely. However, other important malaria vectors such as *Anopheles funestus* (Giles) and *Anopheles arabiensis* (Patton) are often found in habitats readily colonized by *P. clarkii* and there may be interaction. Further investigations on the impact of *P. clarkii* on populations of the aquatic forms of medically important mosquitoes should probably focus on species such as *An. funestus* and *An. arabiensis.*

It is premature to speculate seriously on the role of *P. clarkii* in limiting natural populations of the aquatic forms of mosquitoes. However, in one experiment crawfish reduced the abundance of immature stages of *Culex quinquefasciatus* (Say) by half, relative to controls, in small artificial ponds (G. M. Mkoji, Biomedical Sciences Research Center, Kenya Medical Research Institute, unpublished data). In Kenya, *P. clarkii* appears to be well adapted to small, permanent bodies of water (Hofkin et al. 1991a, Loker et al. 1992) that also serve as breeding sites for disease pathogen-transmitting mosquitoes (Lockhart et al. 1969, Hunter et al. 1993). Crawfish may be useful in the control of mosquitoes in these habitats.

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