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SCIENTIFIC NOTE

THE ROLE OF MOSQUITOES IN THE DIET OF ADULT DRAGON AND DAMSELFLIES (ODONATA)

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ABSTRACT. The flood plains of the Upper Rhine Valley provide excellent conditions for the proliferation of mosquitoes as well as for the development of dragon and damselflies. It could be assumed that mosquitoes belong to the diet of the Odonata and that the latter could be harmed by the reduction of the mosquito population with the purpose of diminishing the massive nuisance for the people living there. A total of 41 adult dragonflies and damselflies were examined by immunoblot for remnants of mosquitoes in their guts. A rabbit antiserum against *Aedes vexans* proteins was used for the immunoblot. Only 3 *Aeshna cyanea* and 1 *Platycnemis pennipes* could be shown to have fed on mosquitoes. In specimens of the genus *Sympetrum* no mosquitoes were detected. It seems very doubtful that mosquitoes are an essential part of the Odonata diet.

KEY WORDS Odonata, Culicidae, predator–prey relationship, diet, mosquitoes

The flood plains of the River Rhine in the Upper Rhine Valley in southwestern Germany provide excellent conditions for the breeding and proliferation of floodwater mosquitoes. Their larvae develop in ephemeral pools that remain after flooding (Becker et al. 2010). To protect the inhabitants of adjacent settlements against mosquito nuisance, the KABS (Kommunale Aktionsgemeinschaft zur Bekämpfung der Stechmückenplage e.V./German Mosquito Control Association) has conducted mosquito control activities in the Upper Rhine Valley since 1976. By applying highly specific formulations based on *Bacillus thuringiensis* var. *israelensis* (*Bti*; de Barjac) to larval habitats, the mosquito populations usually are reduced by about 90% (Becker 1997). The main nuisance mosquito is the floodwater species *Aedes* (*Aedimorphus*) *vexans* (Meigen), followed by *Ae.* (*Ochlerotatus*) *sticticus* (Meigen), *Ae.* (*Aedes*) *rossicus* Dolbeskin, Gorickaja and Mitrofanova, *Ae.* (*Aed.*) *cinereus* Meigen, and *Ae.* (*Aed.*) *geminus* Peus (Becker et al. 2010). In the swampy woodlands, *Ae.* (*Och.*) *cantans* (Meigen) is the major pest species. The flood plains also provide suitable living conditions for about 53 of the total 81 species of Odonata found in Germany (Röske and Höppner 1994), including 32 endangered species. The suitability of the habitat depends mainly on the quality of the habitat waters, the landscape structure, and climatic conditions (Schiemenz 1953, Sternberg and Buchwald 1999, Corbet 2004).

There is a concern that by reducing the mosquito populations, dragon and damselflies could be robbed of a part of their diet and thereby be put in jeopardy. Even though it is known that odonate naiads feed on mosquito larvae in the laboratory (Lee 1967, Miura and Takahashi 1988), they usually do not develop in the highly ephemeral pools of the flood-plain forests. Consequently, other studies have shown that mosquitoes only play a minor role in the food of odonate naiads (Pritchard 1964, Pearlstone 1973, Thompson 1978). But because little is known about the diet of adult dragon and damselflies, the role of mosquitoes as a food source was investigated in this study.

From June to October 1998 and in July 1999, different species of adult Odonata were caught and their gut contents were examined for the remnants of mosquitoes by an immunoblot test method (Greenstone 1996, Hagler 1998). For this purpose, rabbits were immunized with a protein solution of *Ae. vexans* to create an antiserum with which specific mosquito proteins could be detected (Friemel 1991). Only a small number of odonates could be caught because of species protection restrictions. Of the total 41 odonates examined, 16 belonged to the genus *Sympetrum*, 7 to *Aeshna*, 15 to *Platycnemis pennipes* (Pallas), 2 to *Ischnura elegans* (Vander Linden), and 1 *Lestes viridis* (Vander Linden). All insects were caught on-wing during flight with a sweep net in the flood plain forests of the Upper Rhine in the Ortenau District of southwestern Germany. Only 4 *Sympetrum sanguineum* (Müller) and 4 *P. pennipes* individuals originated from areas where microbial mosquito control by *Bti* treatment was conducted. The odonates were killed at −78°C and kept at least at −20°C until examination. The species determination was done according to Bellmann (1993).

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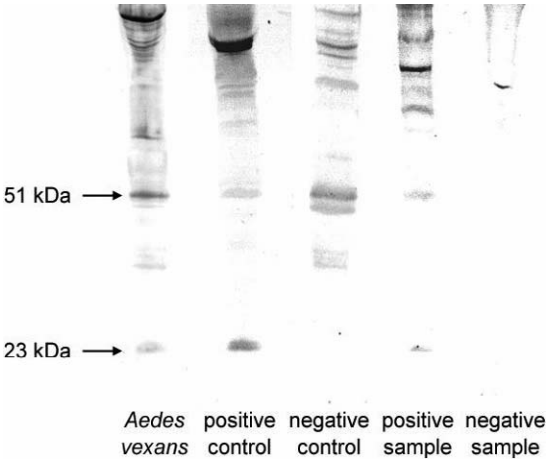

Fig. 1. Results of immunoblots used in the detection of mosquito remnants in dragonflies, with rabbit antiserum used for *Aedes vexans* protein homogenate.

All odonates were caught after floods, which previously had produced a proliferation of mosquitoes. No mosquito control took place during the study period in the vicinity of Rheinau, so the mosquito population was particularly high. To quantify the mosquito abundance, human bait measurements were carried out during the capture of the odonates. Additionally, CO_2-baited encephalitis vector surveillance traps (following Rohe and Fall 1979) were used to monitor the mosquito populations during the study. The species collected were identified according to Mohrig (1969).

Remnants of *Ae. vexans* could be detected by the staining of a 23-kDa protein in the immunoblot. This was considered a positive result (Fig. 1). If this protein was not present, the sample was considered negative. The 23-kDa protein in general could be demonstrated up to a concentration of about 250 µg/ml. This represents a 20× dilution of a homogenate of *Ae. vexans*. An additional protein with a molecular mass of approximately 51 kDa was stained to a 1,000× dilution of *Ae. vexans* homogenate, i.e., up to a concentration of about 5 µg/µl. However, it could also be detected in other Diptera and thus did not indicate specific evidence of Culicidae. The 23-kDa protein was digested the slowest by *Sympetrum* individuals and could still be found in the intestines 12 h after the consumption of mosquitoes. The 51-kDa protein could be detected in the stomach more than 6 h after feeding, but not any longer in the intestine. Also, other species of the Culicinae subfamily could be detected with the antiserum, for example, *Ae. sticticus* and *Culex pipiens* L., but not anopheline spp.

The immunoblots in Fig. 1 show in the first row a homogenate of *Ae. vexans* with a protein concentration of about 0.5 mg/ml, which served as a positive control. In the second row, the homogenate of the gut content of a control dragonfly was applied. A *Sympetrum striolatum* female was fed with 13 *Ae. vexans* 3 h before being killed. A *Chaoborus* sp. in the third row serves as negative control. The fourth row shows a typical positive result in 1 of the animals examined, an *A. cyanea*. In the last row a negative result of a wild-caught *Ae. cyanea* is demonstrated. The mosquito-specific 23-kDa protein is marked, as well as the 51-kDa protein. Altogether, 4 out of a total of 41 dragon and dragonflies could be shown to have fed on mosquitoes (Table 1). Particularly in 3 out of 7 *Aeshna* specimens, mosquito remnants could be detected in the chyme. Two of the positive dragonflies were caught at dusk at the height of mosquito feeding activity and 1 was collected in the morning. Mosquito trap collections during the investigation showed that *Ae. vexans* was the most abundant mosquito species, accounting for almost 80% of the mosquito populations, followed by *Ae. sticticus* (12%) and *Ae. cinereus* (5%).

Table 1. Data on the presence of mosquito remnants tested in the food of wild-caught dragonflies.

Genus/species	Animals tested	Positive	Negative
Aeshna	7	3	4
Sympetrum	16	0	16
Platycnemis pennipes	15	1	14
Lestes viridis	1	0	1
Ischnura elegans	2	0	2
Total	41	4	37

No mosquito remnants were detected in any of the *Sympetrum* specimens. All of the 16 individuals were captured between 1:00 p.m. and 6:00 p.m. Of 15 *P. pennipes* caught, only 5 of them had sufficient quantity of food in the stomach to be studied. In 10 specimens the guts were empty or contained only a very small amount of food. Only 1 of the 5 sufficiently fed females used in the study had mosquito remnants in its guts. This specimen was caught in a *Bti*-treated area. Additionally, 2 *I. elegans* and 1 *L. viridis* showed no evidence of mosquito remnants. The proportion of adult dragon and damselflies that had fed on mosquitoes was surprisingly low, considering that they were mainly collected in areas with mass development of floodwater mosquitoes. From a total of 41 dragonflies and damselflies, food containing remnants of mosquitoes were only detected in 4 individuals, although there was a sufficient abundance of mosquitoes providing potential food sources. The biting activity of mosquitoes in the study area was around 10 females in 2 min. This presumptive mosquito population density should have been sufficient as a potential food source for dragonflies. In extreme cases the biting activity of mosquitoes can reach up to several hundred females in 2 min

(Becker 1997), but this usually lasts only for a few weeks of the year.

Dragon and damselflies are considered opportunistic feeders (Schiemenz 1953), and are therefore not restricted to a particular group of prey. Obviously they hunt the most readily available prey. This may originate from very different insect groups, for example, chironomids, flies, horseflies, and mosquitoes (Diptera), Hymenoptera, Lepidoptera, Ephemeroptera, Coleoptera, and also from their own taxon, Odonata (Sukhacheva 1996). The role of mosquitoes for odonates strongly depends on the predating behavior of the respective odonate species. *Aeshna cyanea* was the only species in this study that considerably had fed on mosquitoes. Many *Aeshna* spp. are twilight hunters (Schiemenz 1953), which also hunt in low light in the evening hours and as patrolling hunters prey along roadsides and in clearings searching the vegetation, an activity which was also observed in this study. This favors them for hunting mosquitoes, which mainly become active at twilight. This results in an overlap of the main activity phases, which is an important requirement for a predator–prey relationship. Many odonate species that are only active during the day do not meet this requirement. For example, *Sympetrum* species could not be observed later than 6:00 p.m. In addition, they act as ambushing predators, snatching prey as it flies by, which is typical for most of the Libellulidae (Sternberg and Buchwald 1999). They typically prey at the water's edge, or at least in an open field. Furthermore, mosquitoes should not be a target for odonate species hunting over open waters, such as *Anax* spp. Little can be concluded about damselflies (Zygoptera) based on this study. Damselflies hunt under the protection of vegetation; they could also be assumed to be mosquito predators. In addition, they appear more suitable than Aeshnidae, which specialize in larger prey, due to their size. The only *P. pennipes* that had fed on mosquitoes in this study was out of a mosquito controlled area with lower mosquito abundance. Probably, a temporal and spatial overlap of habitats occurs rarely for damselflies as well because they hunt mainly during the day and in sunny areas that are typically avoided by mosquitoes.

This study provides no evidence that mosquitoes play an essential role in the diet of adult dragon and damselflies. Furthermore, it needs a very detailed perspective on single species with precise knowledge of its ecology and behavior. Additionally the development of mosquitoes and odonates is not synchronous, and therefore mosquitoes might be a relevant food resource for a few species only for a short period after mass development.

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