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MITES ON ZYGOPTERA, WITH PARTICULAR REFERENCE TO *ARRENURUS* SPECIES, SELECTION SITES AND HOST PREFERENCES

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Larval mites of several *Arrenurus* spp. are found as parasites on Zygoptera. Data from Poland on prevalence, loads, and host specificity are presented. The larval mites are identified and their site selection and host preferences recorded. 7 Zygoptera spp. and 7 spp. of arrenurid mite have been studied. Particular attention has been paid to *Coenagrion puella* and its parasites. New host records are included.

INTRODUCTION

Several orders of aquatic insects, whose imagos live permanently out of water, are parasitized by larval mites. They are found most frequently on the imaginal stages of insects but the immature stages can also be infested. As a result of recent descriptions, based on larval morphologies, it is now possible to identify, with some degree of certainty, the larval parasites of zygopterans. The recent descriptions of arrenurid larvae (ZAWAL, 2006a, 2006b, 2006c, 2006d, 2007) make it possible not only to identify the species of parasitic mite involved but also to investigate their host preferences and attachment sites on damselflies. In this study, seven *Arrenurus* species have been found on seven Zygoptera species. In the case of *Coenagrion puella* four species of parasitic mite are recorded. The selection sites on their hosts have been noted.

The life cycle of water mites involve the following stages: egg, larva, nymph and adult. Between the larval and nymphal stages and between the nymphal and adult

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stages, there are quiescent stages in which a transformation takes place. These are referred to as resting stages - post larval resting stage 1 (nymphochrysalis) and post larval resting stage 2 (imagochrysalis). Arrenurid larvae are true parasites and exploit their insect hosts for both food and dispersal. In odonates, water mite larvae also form a phoretic association with the last instar larva of the damselfly (ZAWAL, 2004a), and when the host emerges they leave the exuviae of their larval host transferring to the newly emerged adult odonate to become parasitic. Engorgement on the host may take several days and the larvae can remain on their hosts for up to two weeks. ÅBRO (1990) noted that in *Enallagma cyathigerum* and *Coenagrion hastulatum* the greatest number of mites on an individual occurred on its maiden flight, the number decreasing through adult life. Furthermore, individuals with a heavy load tended to disappear when still young, often before their reproductive phase. Conversely, in *Pyrrhosoma nymphula* and *Lestes sponsa* the number of mites started off relatively low but increased on repeated visits to the water for reproduction, the load thus increasing with adult age.

Mites have been known to live on the surface of Odonata since the eighteenth century at least. DE GEER (1778) published a description and drawings of what was referred to as *Acarus libellulae.* SMITH & OLIVER (1976) and SMITH (1988) examined and reviewed the host-parasite interactions and impact of water mites on insects in general and the relationship between mites and odonates has been reviewed more recently by CORBET (1999).

Species of *Arrenurus* have previously been described by several authors on a variety of insect hosts including those on damselflies (CASSAGNE-MEJEAN, 1966; DAVIDS, 1997; MITCHELL, 1959; MÜNCHBERG, 1935, 1963 and STECHMANN, 1977). They attach to the ventral surface of the host mainly in the posterior part of the thorax but are also found on abdominal segments and along wing veins. DAVIDS (1997) reviewed the literature, based on CASSAGNE-MEJEAN (1966), MÜNCHBERG (1935, 1963) and STECHMANN (1977) and recorded the known relationships between odonates and water mite species from northern Europe. He lists the following zygopterans parasitised by 18 different species of larval arrenurids: *Lestes barbarus, L. dryas, L. sponsa, Coenagrion hastulatum, C. mercuriale, C. puella, C. pulchellum, C. scitulum, Enallagma cyathigerum, Erythromma lindenii, E. najas, Ischnura elegans, Pyrrhosoma nymphula, Platycnemis latipes* and *P. pennipes.*

MATERIAL AND METHODS

Collections of adult odonates took place in the summer months (June and July 2005 and May - August 2006), using both pond and entomological nets, at sites near Szczecin, Poland. Several sites have been used. One pond at Uroczysko and four ponds at Dolina 7 Mlynow (the valley of seven mills) were sampled. Odonates were also collected at peat bogs near the villages of Zaklodzie and Sikorki but these yielded no larval mites. In 2006, several sites near Szczecin were sampled which in-

cluded a peat bog, an eutrophic pond, a dystrophic lake and alder carr.

Infected and uninfected damselflies were preserved in 70% alcohol. Subsequently, samples of attached larvae were counted, removed and mounted in Hoyers medium. Selection sites and numbers were noted. Care had to be taken to remove all of the larvae, some of which lay on top of each other and would have been missed in an in situ count.

Seven species of Zygoptera hosts have been examined for larval arrenurids. They are: *Coenagrion puella* female and male, *Coenagrion pulchellum* male, *Erythromma najas* female, *Ischnura elegans* female, *Lestes dryas* female and male, *Lestes sponsa* female and male and *Pyrrhosoma nymphula* female and male. The identification of *Arrenurus* species was based on larval morphology and ZAWAL (2006a, 2006b, 2006c, 2006d, 2007) has produced taxonomic descriptions for the identification of several larval arrenurids.

RESULTS

HOST SPECIFICITY AND NEW HOST RECORDS

Seven *Arrenurus* species were found on the adults of the seven odonate species examined (Tab. I). Of the latter *Coenagrion puella* was by far the most numerous. For the first time *A. bicuspidator* has been recorded on *P. nymphula*, *A. cuspidator* on *C.puella* and *E. najas*, *A. cuspidifer* on *L. dryas* and *A. tricuspidator* on *L. sponsa*.

PREVALENCE AND INTENSITY OF INFESTATION

A total of 591 specimens were examined for mites, made up of 77% of *C. puella* and 23% the other six species. Of the total, 128 were found to be parasitised giving an overall prevalence of 21.7%; the prevalence for *C. puella* alone was 23.8% and a figure of 14.6% for all taxa except *C. puella*. The mean density in *C. puella* was 8.1 but was higher for other species (20.5). The maximum number of mites found

Table I
Arrenurus larvae found on zygopterans

Zygoptera	*Arrenurus*						
	bruzelli	*bicuspidator*	*cuspidator*	*cuspidifer*	*maculator*	*papillator*	*tricuspidator*
Coenagrion puella	/	/	/	-	/	-	-
Coenagrion pulchellum	-	-	/	-	/	-	-
Erythromma najas	-	-	/	-	-	-	/
Ischnura elegans	-	-	/	-	-	-	/
Lestes dryas	-	-	-	/	-	/	-
Lestes sponsa	-	-	-	-	-	-	/
Pyrrhosoma nymphula	/	/	-	-	-	-	-

on an individual damselfly was on a female *E. najas* (101), the next highest number being 82 on a female *C. puella* (Tab. II).

Table II
Numbers of mites and damselflies

	All taxa of damsels	All taxa except *C. puella*	All *C. puella*
Number of damselflies	591	137	454
Number of damsels with mites	128	20	108
Number of mites	1282	409	873
Prevalence	21.7%	14.6%	23.8%
Intensity	0-101	0-101	0-82
Mean Density	10.0	20.5	8.1
Abundance	2.2	3.0	1.9

A total of 1282 mites were found. Of these 62.5% were recorded on the thorax, 35.3% on the abdomen and 2.25% in the intersegmental area between the thorax and the abdomen. Of the mites recorded on *C. puella,* 14.5% were found on the abdomen, 82.3% on the thorax and 3.2% between the two. In the combined figures for the other host species, 79.7% were found on the abdomen and only 20.3% on the thorax (Tab. III). Those mites recorded from the abdomen were mainly found on segments 4 to 7, although all abdominal segments from 1-9 were used as attachment sites. On the thorax, mites occurred most frequently between and behind legs 2 and 3 as well as behind the 3rd pair of legs (Tab. III).

SPECIES OF MITE AND THEIR SELECTION SITES ON THE HOST

Samples of the larval mites were removed and identified, a total of 412 in all (Tab. IV). In addition 38 others were either identified to *Arrenurus* species only or their site selection was not recorded. The predominant species are *A. cuspidator* (38%) and *A. maculator* (31 %) and these two species together with *A. tricuspidator* (13 %) make up 82 % of all the larvae found. *A. cuspidifer* and *A. papillator* were both rare but that is most likely a reflection of the scarcity of their host (*Lestes dryas*) in the samples.

Almost all of the larval mites were found on the ventral side of the mid and posterior parts of the thorax and on certain segments of the abdomen (Tab. IV).

Table III
Location of larval mites on damselflies

	Totals	Between/at base of legs		Behind leg 3	Interseg. thorax-abd	Abdominal segment								
		1/2	2/3			1	2	3	4	5	6	7	8	9
C. puella	873	12	288	418	28	47	10	12	24	19	14	1	0	0
All taxa except *C. puella*	409	8	33	42	0	7	2	24	58	91	70	67	6	1
Total mites	1282	20	321	460	28	54	12	36	82	110	84	68	6	1

Table IV
Water mite larvae on particular segments of all Zygoptera, based on a sample of 412 of the 1282 mites found in this survey

Arrenurus	Between/at base of legs		Behind leg 3	Interseg. thorax-abd.	Abdominal segment							
	1/2	2/3			1	2	3	4	5	6	7	Total
bicuspidator	2	12	5	4	-	-	-	-	-	-	-	23
bruzelli	9	30	11	-	-	-	-	-	-	-	-	50
cuspidator	3	69	38	-	-	-	-	1	16	14	17	158
cuspidifer	-	-	1	-	-	-	-	-	-	-	-	1
maculator	-	9	82	21	15	-	-	-	-	-	-	127
papillator	-	-	1	-	-	-	-	-	-	-	-	1
tricuspidator	1	6	9	-	3	9	6	7	6	4	1	52
Total	15	126	147	25	18	9	6	8	22	18	18	**412**

Note: An uncertain *A. claviger* specimen has also been found

Mite larvae have also been noted, infrequently, on other parts of the body such as the prothorax, eye, head and neck but have been ignored in this work. Only three larval mite species, namely *A. cuspidator, A. maculator* and *A. tricuspidator,* were found on the abdomen of the damselflies and these occur on the anterior and middle segments. *A. maculator* was only found on the first segment while *A. cuspidator* was absent from the first three segments. All three species were also found on the thorax and *A. bicuspidator* and *A. maculator* were found in the intersegmental region between the thorax and abdomen (Tab. IV).

The most commonly infected zygopteran was *C. puella;* a total of 454 individuals have been examined for mites, yielding 108 infected specimens, with a total of 872 larval mites (prevalence 23.8%, intensity 0-82, mean density 8.1). Roughly one third of these mites have been identified and their selection sites noted. Four *Arrenurus* species were recorded from *C. puella* namely *A. bicuspidator, A. bruzelli, A. cuspidator* and *A. maculator* (Tab. V).

292 mite larvae have been identified to species from *C. puella* and they were mainly located on the thorax (Tab. III). An additional 9 larvae were identified to the genus only. *A. cuspidator* (36%) and *A. maculator* (45%) make up 81 % of all the larvae recorded on *C. puella*, the prevalence of

Table V
Arrenurus species and number of individuals on infected *Coenagrion puella* from particular regions of the body, based on a sample of 292 of the 872 mites found in this survey

Arrenurus	Between/at base of legs		Behind legs 3	Interseg. thorax-abd.	Abdomen seg. 1	Total
	1/2	2/3				
bicuspidator	-	12	3	4	-	19
bruzelli	9	29	-	-	-	38
cuspidator	2	68	35	-	-	105
maculator	-	9	100	6	15	130
Total	11	118	138	10	15	**292**

the other species being *A. bruzelli* (13 %) and *A. bicuspidator* (7 %). *A. cuspidator* occurs mainly between, and at the base of, legs 2 and 3 and behind the third pair of legs, whereas *A. maculator* is found almost exclusively behind the third pair of legs and was the only species found on the abdomen of *C. puella*. Both *A. bicuspidator* and *A. maculator* were the only two that occurred in the intersegmental region between the thorax and abdomen.

DISCUSSION

Several *Arrenurus* species have larvae that parasitize damselflies; in this study most commonly *A. maculator* and *A. cuspidator,* although five other species of *Arrenurus* have been recorded. ANDERSON (2002), working on a large museum collection of odonates in Minnesota, USA, found that over 95% of the mite larvae were *Arrenurus* spp., although a species of *Limnochares* was also recorded. Zygoptera host lists for the various species of *Arrenurus* have been drawn up by CASSAGNE-MEJEAN (1966) and DAVIDS (1997). Several new hosts records are reported in the present paper but other European workers, including CASSAGNE-MEJEAN (1966) and DAVIDS (1997), have recorded larval species of *Arrenurus* on damselflies that have not been found during the present work. With further collecting and recording, more infected damselfly species and other species of *Arrenurus* will undoubtedly be found. DAVIDS (1997) lists 18 parasitic larval mites of this genus but whether all of these are valid species is currently under review, especially since some of them date back to work published some 70 years ago. CASSAGNE-MEJEAN (1966) lists nine species, including *A. tricuspidator, A. bruzelli* and *A. maculator*.

Arrenurus larvae show a clumped distribution on their hosts, as demonstrated by several workers including ANDRES & CORDERO (1998) and ROLFF (2000). ANDRES & CORDERO (1998) found that, in the case of the damselfly *Ceriagrion tenellum*, mites aggregated strongly on their host and 98% of immature adult males and females were parasitized, a figure far higher than recorded in the present study. In this, mites showed a preference for the areas between and behind the second and third pairs of legs and, when they occurred on the abdomen, for anterior and middle segments. They appear to prefer sites where the cuticle is less sclerotised such as the intersegmental areas, where their mouthparts might more easily be inserted, as the present work and HOFFMAN & ANDERSON (2001) indicate. HOFFMAN & ANDERSON (2001) examined 2591 adult Zygoptera made up of 35 species from a museum insect collection and found an infestation level in the Coenagrionidae of 16%, which agrees fairly closely with the overall figure in this study but, unlike here, mites were most frequently attached to the mid thorax and the seventh abdominal segment. In another study, ZAWAL (2004b) found the prevalence in *C. puella* to be 54%, the larvae preferring the mesothorax, the proximal part of the metathorax and the anterior seg-

ments of the abdomen.

ROLFF (2000), who worked on *C. puella* parasitized by *A. cuspidator* from a pond where it was the only host and on *C. hastulatum* which co-occurred in a second pond, found that prevalence was close to 100% and that the mean daily abundance ranged from 1 to 45 mites per host. McKEE et al. (2003) recorded up to 62 *Arrenurus* per infected host in New Zealand but mean burdens were not related to the sex or size of the host. CASSAGNE-MEJEAN (1966) recorded loads that reached 150 for *A. cuspidifer* on *Ischnura elegans*. CORBET (1999), referring to the parasitic larval stage, has stated that, "mite loads vary between years, populations and individuals within a population". It is clear from previous work that there are considerable variations in both prevalence and loads. Care must therefore be taken in drawing conclusions from the results of isolated studies on single populations of damselflies and their parasites.

As with other parasitic infections, many hosts were found without mites, some with just a few parasites and only a small number of damselflies had heavy loads. Prevalence overall was 21.7%. Resource partitioning can occur when different hosts are used but, when the same host is utilised, different species of mite may remain segregated in different ways including their different sites of attachment on the host (LANCIANI, 1970). Some mites detached from their hosts and were found at the bottom of tubes containing the preservative, having presumably done so during fixation. These have been discounted in the present figures because frequently several damselflies were fixed in one tube from a particular collecting site.

There may be distinct attachment sites on a single host species as MITCHELL (1968) showed in the case of two arrenurid species living on the same species of damselfly. One was found on the host mesothorax and the other on the abdomen; the latter, under crowded conditions, may move to more anterior sites on the abdomen. Although there was nothing to suggest such a clear distinction as MITCHELL (1968) found, the sites most commonly selected in the present work were between the second and third legs and behind the third legs, and larvae found on the abdomen were frequently from the intersegmental areas between the thorax and abdomen and the anterior and middle abdominal segments but not the posterior ones The only species found on the abdomen were *A. cuspidator, A. maculator* and *A. tricuspidator* with *A. maculator* the only mite found on the abdomen of *C. puella.* Some of the species appear to have broad selection sites, for example *A. cuspidator* and *A. tricuspidator* have been found on the thorax as well as on the abdomen, and *A. bruzelli* has a wide distribution on the thorax. BOTMAN et al. (2002) examined site selection in two arrenurid species on *Ischnura posita* and found species specific selection sites. *A. major* attached to the thorax and abdominal segments one to three, whereas *A. americanus* attached to abdominal segments five to eight. SMITH (1988) stated that, although mite larvae have characteristic sites on their hosts, these might vary with the host species.

With regard to *C. puella,* where four *Arrenurus* species have been found, the distribution of *A. maculator* is particularly interesting. Its larva appears to occur mainly behind the third pair of legs, but also in the intersegmental region between thorax and abdomen and the anterior region of the abdomen. *A. cuspidator*, on the other hand, occurs further forward on the host's body, mainly between and at the base of legs two and three, although it also occurs behind the 3rd pair of legs. This may be the result of competition for a selection site and similar to that recorded by BOTMAN et al. (2002). However, until further work is carried out on the *Arrenurus* species and their identification and distribution on the host, no firm conclusions can be drawn.

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