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BDS

INSTRUCTIONS TO AUTHORS

Authors are asked to study these instructions with care and to prepare their manuscripts accordingly, in order to avoid unnecessary delay in the editing of their manuscripts.
- Word processed manuscripts may be submitted in electronic form either on disk or by e-mail.
- Manuscripts should be one and a half spaced, on one side of the page only and with margins at least 25mm on both sides and top and bottom. Footnotes should be avoided.
- Use of these terms is acceptable: 'exuvia' for cast skin (plural: 'exuviae'); 'larva' (instead of 'naiad' or 'nymph'); 'prolarva' to designate the first larval instar.
- Dates in the text should be expressed in the form: 24 July 2010.
- References cited in the text should be in the form '(Longfield, 1949)' or '...as noted by Longfield (1949)'. All references cited in the text (and only these) should be listed alphabetically at the end of the article in the following forms:
  Hammond, C.O. 1983. *The Dragonflies of Great Britain and Ireland* 2nd Edition (revised by R. Merritt), Harley Books, Colchester, 116pp.
  Longfield, C. 1949. The Dragonflies of the London area. *The London Naturalist* **28**: 90-98.
- Titles of journals should be written out in full.
- Figures, plates and tables should be presented on separate, unnumbered pages.
- Legends for figures, plates and tables should be presented together in sequence on separated, unnumbered pages.
- The legend for each table and illustration should allow its contents to be understood fully without reference to the text.

Please refer to a recent issue of the journal for further style details.

SCIENTIFIC AND ENGLISH NAMES OF BRITISH ODONATA

ZYGOPTERA	DAMSELFLIES		
Calopteryx splendens	*Banded Demoislle*	*Aeshna juncea*	*Common Hawker*
Calopteryx virgo	*Beautiful Demoiselle*	*Aeshna mixta*	*Migrant Hawker*
Lestes barbarus	*Southern Emerald Damselfly*	*Anax ephippiger*	*Vagrant Emperor*
Lestes dryas	*Scarce Emerald Damselfly*	*Anax imperator*	*Emperor Dragonfly*
Lestes sponsa	*Emerald Damselfly*	*Anax junius*	*Green Darner*
Lestes viridis	*Willow Emerald Damselfly*	*Anax parthenope*	*Lesser Emperor*
Sympecma fusca	*Winter Damselfly*	*Brachytron pratense*	*Hairy Dragonfly*
Coenagrion armatum	*Norfolk Damselfly*	*Gomphus flavipes*	*Yellow-legged Clubtail*
Coenagrion hastulatum	*Northern Damselfly*	*Gomphus vulgatissimus*	*Common Club-tail*
Coenagrion lanulatum	*Irish Damselfly*	*Cordulegaster boltonii*	*Golden-ringed Dragonfly*
Coenagrion mercuriale	*Southern Damselfly*	*Cordulia aenea*	*Downy Emerald*
Coenagrion puella	*Azure Damselfly*	*Somatochlora arctica*	*Northern Emerald*
Coenagrion pulchellum	*Variable Damselfly*	*Somatochlora metallica*	*Brilliant Emerald*
Coanagrion scitulum	*Dainty Damselfly*	*Oxygastra curtisii*	*Orange-spotted Emerald*
Erythromma najas	*Red-eyed Damselfly*	*Leucorrhinia dubia*	*White-faced Darter*
Erythromma viridulum	*Small Red-eyed Damselfly*	*Leucorrhinia pectoralis*	*Large White-faced Darter*
Pyrrhosoma nymphula	*Large Red Damselfly*	*Libellula depressa*	*Broad-bodied Chaser*
Enallagma cyathigerum	*Common Blue Damselfly*	*Libellula fulva*	*Scarce Chaser*
Ischnura elegans	*Blue-tailed Damselfly*	*Libellula quadrimaculata*	*Four-spotted Chaser*
Ischnura pumilio	*Scarce Blue-tailed Damselfly*	*Orthetrum cancellatum*	*Black-tailed Skimmer*
Ceriagrion tenellum	*Small Red Damselfly*	*Orthetrum coerulescens*	*Keeled Skimmer*
Platycnemis pennipes	*White-legged Damselfly*	*Crocothemis erythraea*	*Scarlet Darter*
		Sympetrum danae	*Black Darter*
		Sympetrum flaveolum	*Yellow-winged Darter*
ANISOPTERA	DRAGONFLIES	*Sympetrum fonscolombii*	*Red-veined Darter*
Aeshna affinis	*Southern Migrant Hawker*	*Sympetrum pedemontanum*	*Banded Darter*
Aeshna caerulea	*Azure Hawker*	*Sympetrum sanguineum*	*Ruddy Darter*
Aeshna cyanea	*Southern Hawker*	*Sympterum striolatum**	*Common Darter**
Aeshna grandis	*Brown Hawker*	*Sympetrum vulgatum*	*Vagrant Darter*
Aeshna isosceles	*Norfolk Hawker*	*Pantala flavescens*	*Wandering Glider*

* Includes dark specimens in the north-west formerly treated as a separate species, *Sympetrum nigrescens* Highland Darter.

Species list in accordance with Davies, D.A.L. & Tobin, P. (1984 & 1985) The Dragonflies of the World: A systematic list of the extant species of Odonata. Vols 1 & 2.

On the relationship between the Small Red Damselfly *Ceriagrion tenellum* and the terrestrial mite *Leptus killingtoni*

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Summary

Larvae of the terrestrial mite, *Leptus killingtoni* were identified on a population of *Ceriagrion tenellum* on the East Devon Pebblebed Heaths in 2011. An investigation was undertaken on the interaction between these species during the flight period in 2012. In total 567 individuals (382 males and 185 females) were caught and marked and the location of a total of 808 mites were noted (498 on first capture and a further 310 on recaptures). The highest numbers of *L. killingtoni* were seen in the middle and driest period at the end of July. Only 19% of immature *C. tenellum* were found to have mites, whereas 36% of male and 49% of female mature damselflies had mites. Paired females were more likely to be infested than unpaired females and males (whether paired or not). Mites were recorded most often from areas more difficult to groom, with 26.6% recorded on the ventral surface of the thorax (and especially between the legs), 20.9% on the abdomen and 17.3% on the femur. Female *melanogastrum* were recaptured nearly twice as often as *typica*, despite similar numbers being marked.

Introduction

The genus *Leptus* has a six-legged, orange or red larval stage which is an ectoparasite of arachnids and insects (Baker & Seldon, 1997). The nymphs and adults are eight-legged, free-living predators. Turk first described *Leptus killingtoni* from Dorset specimens sent to him by Killington and Bathe (Turk, 1945) and it has since been re-described (Southcott, 1992). *Leptus killingtoni* has now been recorded on twelve odonate hosts (Killington & Bathe, 1946; Lorenzo-Carballa *et al.*, 2011; Kerry & Baker, 2012).

Following a pilot study in 2011 (Kerry & Baker, 2012), when the larvae of the terrestrial mite, *L. killingtoni* were identified on a population of the Small Red Damselfly *Ceriagrion tenellum* on the East Devon Pebblebed Heaths, a more thorough investigation was undertaken on the interaction between these

species from 18 June to 22 September 2012. The objectives of this study were to investigate the prevalence of *L. killingtoni* on the population of *C. tenellum* throughout its flight period, to investigate any differences in infestation between immatures and adults, males and females, and paired and unpaired adults of *C. tenellum* and to determine if *L. killingtoni* has any preferred attachment locations.

Material and Methods

Description of the Study Site

The study area is located on a gentle, south-facing slope on Colaton Raleigh Common on the East Devon Pebblebed Heaths Site of Special Scientific Interest, Special Protection Area and Special Area of Conservation, at SY048868 (Fig. 1), approximately nine miles south-east of Exeter and five miles west of Sidmouth. These heaths are owned and managed by Pebblebed Heaths Conservation Trust (Clinton Devon Estates).
The study site (approximately 0.15ha) holds two small flushes of M14 *Schoenus*
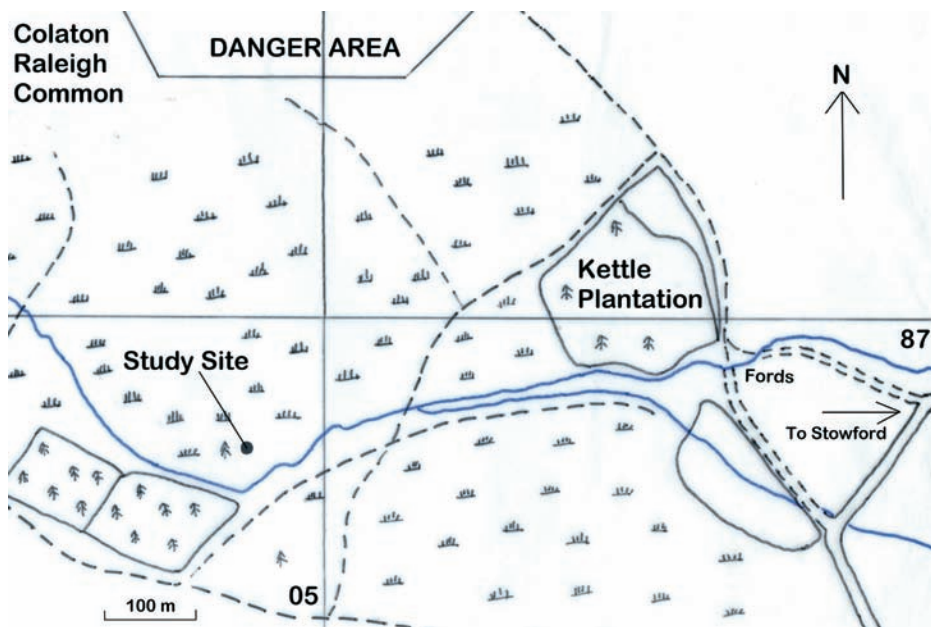
Figure 1. The location of the study site on Colaton Raleigh Common, Devon. British National Grid Reference SY048868.

nigricans (Black Bogrush) – *Narthecium ossifragum* (Bog Asphodel) mire (National Vegetation Classification Rodwell *et al*., 1991), one to the north west and one to the east of a small, shallow, open pool (approximately 6 m x 15 m). To the west of this pool there is a mosaic of tussocky *S. nigricans* and *Molinia caerulea* (Purple Moor Grass) and open water, with deep silt, covering some 18 m x 26 m. The small pool is partly shaded by a large pine tree but has more open water, with occasional *Hypericum elodes* (Marsh St John's Wort) and *Potamogeton* spp (Pondweed). Around the edges, *M. caerulea, Rhyncospora alba* (White Beak-sedge) and *N. ossifragum* occur, along with *Sphagnum* spp. and *Anagallis tenella* (Bog Pimpernel). The flushes are composed of dense tussocks of *S. nigricans* and *M. caerulea* with shallow, often shaded, runnels and pools between them. The base-rich water of the flushes comes from a spring-line at the base of a small escarpment to the north. The water is then held on a more level area with deep silt among *M. caerulea* tussocks before flowing down the slope in small, shallow, braided runnels. These runnels flow south to a larger stream with a pebbly bottom, running east, bounded to the south by a steep tree-covered slope. The surrounding vegetation is influenced by the more acid nature of the Pebblebed Heaths and holds shorter, more exposed and generally drier M16 *Erica tetralix* (Cross-leaved Heath) – *Sphagnum compactum* wet heath, with occasional damper areas delineated by stands of *M. caerulea* or *S. nigricans*.

Methods

Visits were carried out on 40 occasions from 18 June to 22 September 2012 when the weather conditions were suitable (although not always ideal). The study area was thoroughly searched on each visit, the length of visit being dependent on the weather. Individuals of *Ceriagrion tenellum* were caught with an entomological net, checked for *Leptus killingtoni* and identified by writing a number on the left forewing of each damselfly using a black permanent marker pen. Immatures were not marked but occasionally they could be gently caught by hand and checked for *L. killingtoni*. If immatures could not be caught they were checked using close-focus binoculars but it was not possible to see the ventral part of the thorax of these individuals. Females were recorded as being either *typica* (bronze-black and red) or *melanogastrum* (dark bronze) morphs. The uncommon female red *erythrogastrum* form was not seen at this site.

Pairs were gently separated so that they could be checked for *L. killingtoni* and any previously unmarked individuals were marked. Occasionally, pairs remained together during handling. Some individuals were recaptured later on the same day with different partners. These individuals were only recorded again if the number of *L. killingtoni* had changed in the meantime. Individuals were usually released near where they were caught.

Results

The weather in summer 2012 was often cool, wet and windy, with more than double the local average amount of rainfall for June to September (457 mm compared to the 227 mm average for 1988-2011).   339.5 mm of rain were recorded over the study period, falling on 37 of the 97 days.

Ceriagrion tenellum

Five individuals were caught on 18 June (3 males and 2 immatures); although this was not the first day of emergence, it was near the beginning of the flight period. The first female *typica* was caught on 25 June and the first *melanogastrum* on 29 June; the last of these two forms were caught on 5 and 13 September respectively. Immatures were present from 18 June to 30 July. The last male was caught on 18 September. A visit to the site on 22 September yielded no sightings, indicating that the flight period was almost certainly over by this date, especially as the weather deteriorated after that.

The first recapture was on 5 July. In total 567 individuals (382 males and 185 females) were caught and marked. Of the 185 females, 95 were of the form *melanogastrum* and 90 were *typica* (Table 1). For both female forms there were approximately equal numbers caught as singletons and paired with a male (Table 2A). A total of 216 unique individuals were subsequently recaptured at least once (173 males and 42 females). Although both of the above female forms were present throughout most of the study period and the numbers initially caught of each type were similar, female *melanogastrum* were recaptured nearly twice as often as female *typica*. This was not quite significant for individuals recaptured at least once (but not on the same day) ($\chi^2 = 3.64$ [for significance at P<0.05 χ^2 should be >3.84]) (Table 2B).

Average lifespans indicate that males live rather longer than females and that *melanogastrum* females outlive *typica* females (Table 1). Mating was first observed on 14 July and the last pair was caught on 8 September. A total (all capture data including multiple recaptures) of 141 pairs were caught (110 in tandem and 31 in the wheel formation). In 76 cases the male was paired with a *melanogastrum* female and in 63 with a *typica* female (two pairs escaped before the female form could be identified). When comparing only the number of uniquely marked females recaptured in pairs after the day that they were marked, i.e. 18 *melanogastrum* and 11 *typica* there was no significant difference. Nine of the *melanogastrum* females and two of the *typica* females recaptured in pairs on a day after being marked were also recaptured on subsequent day(s). One of

Table 1. Number marked, average lifespan and longest-lived recorded individuals of *Ceriagrion tenellum* adults.

	Number marked	Average lifespan (days)	Longest-lived individual	
			(days)	First and last dates
Male	382	16.35	55 days	20 July-13 Sept
Female (overall)	185	14.47		
melanogastrum	95	15.89	42 days	23 July-3 Sept
typica	90	11.80	32 days	2 Aug-3 Sept

Table 2. Comparison between numbers marked and recaptured of female *melanogastrum* and *typica* forms. (A) initial marking, (B) marked individuals recaptured at least once after their first day of capture. *4 *melanogastrum* recaptured as a singleton and in a pair; 1 *typica* recaptured as a singleton and in a pair.

A

Female	Marked as a singleton	Marked in a pair	Total marked
melanogastrum	50	45	95
typica	44	46	90
Total	94	91	185

B

Female	Recaptured as a singleton	Recaptured in a pair	Total recaptured
melanogastrum	13	18	27
typica	5	11	15
Total	18	29	*42

Table3. The number of *Ceriagrion tenellum* caught without and with *Leptus killingtoni*.

	Immature	Male	Female	Female	
				mel.	typ
Without L. killingtoni	21	244	95	47	48
With L. killingtoni	5	138	90	48	42
Total	26	382	185	95	90

these *melanogastrum* females and one of the *typica* females had, respectively, three and four partners in addition to the one they were first caught with.

Leptus killingtoni

The terrestrial larval mite *Leptus killingtoni* was recorded throughout the study period, with highest numbers seen in the middle and driest period at the end of July. No other mite species were observed on *C. tenellum* during this study.

Only 19.2% of immature *C. tenellum* were found with *L. killingtoni*. In mature damselflies this rose to 36.1% for males and 48.6% for females (Table 3). There was no significant difference between the numbers of *typica* and *melanogastrum* forms found with *L. killingtoni* ($\chi^2 = 0.27$). However, there was a significantly higher proportion of parasitised females than males ($\chi^2 = 8.14$, P<0.01) (Table 3). The range of infestation on first capture of those *C. tenellum* with *L. killingtoni* was from one to nine, with most individual damselflies having one or two mites. The average mite load per individual with mites was lower in male (1.83) compared to female (2.63) *C. tenellum*, with 55.8% of males and 42.2% of females bearing a single mite (Table 4).

The percentage of males with *L. killingtoni* remained about the same from initial marking up to the second recapture but decreased in subsequent recaptures. In contrast the percentage of females with *L. killingtoni* increased from marking to the second recapture. However, only two females were recaptured more than twice (Table 5).

Leptus killingtoni and paired Ceriagrion tenellum

One male and seven females were caught again on the same day with a different partner; these were likely to have changed partners as a result of disturbance during marking and checking for *L. killingtoni*. One pair was separated, marked,

Table 4. The number of *Ceriagrion tenellum* caught with different numbers of *Leptus killingtoni*.

No. of mites	Number of *C. tenellum* caught				
	Imm	Total males	Total females	Female *mel*	Female *typica*
1	4	77	38	18	20
2	1	38	17	9	8
3	0	6	6	2	4
4	0	9	15	11	4
5	0	5	4	1	3
6	0	2	4	4	0
7	0	0	5	3	2
8	0	0	1	0	1
9	0	1	0	0	0
Total	5	138	90	48	42

Table 5. Data for individuals caught with *Leptus killingtoni* on marking and on subsequent recapture(s). Individuals recaptured on the same day with the same number of *L. killingtoni* are excluded but those recaptured on the same day with a different number of *L. killingtoni* are included.

% with *L. killingtoni*	Males			Females		
	Number	%	Range	Number	%	Range
Marking	138	36.1	1 to 9	90	48.6	1 to 8
1st recapture	68	39.5	1 to 7	25	58.1	1 to 14
2nd recapture	30	35.3	1 to 9	9	64.3	1 to 8
3rd recapture	8	15.4	1 to 5	1	20	1
4th recapture	5	18.5	1 to 3	1	100	1
5th to 11th recapture	7	31.8	1 to 2	0	0	0

released and immediately recoupled. Four pairs stayed in tandem while they were being handled.

Taking first captures only, about one third of paired males, unpaired males and unpaired females had *L. killingtoni* (31.8%, 37.0% and 31.9% respectively), whereas almost two thirds of paired females (65.9%) were infested with *L. killingtoni* (Table 6).   Indeed, there was a highly significant difference when comparing paired females to the other three groups ($x^2 = 29.84$, P<0.001). Taking all captures and recaptures into account the figures remained very similar with 29.8% of paired males, 35.1% of unpaired males and 37.3% of unpaired females having *L. killingtoni* compared to 62.9% of paired females ($x^2 = 38.71$, P<0.001).

Location of *Leptus killingtoni*

Including all captures and recaptures a total of 808 *L. killingtoni* were recorded. Of the 498 *L. killingtoni* recorded at first capture 65 (13.1%) were found on the head and pronotum, 192 (38.6%) on the thorax, 100 (20.1%) on the abdomen, 134 (26.9%) on the legs and 7 (1.4%) at the base of the wings. Of those on the

Table 6. Comparison between the numbers of paired and unpaired males and females of *Ceriagrion tenellum* without and with *Leptus killingtoni*. (A) first captures only, (B) all captures and recaptures (excluding individuals recaptured on the same day with the same number of *L. killingtoni*).

A

	paired males	unpaired males	paired females	unpaired females
No *L. killingtoni*	45	199	31	64
With *L. killingtoni*	21	117	60	30
Total	66	316	91	94

B

	paired males	unpaired males	paired females	unpaired females
No *L. killingtoni*	92	399	49	74
With *L. killingtoni*	39	216	83	44
Total	131	615	132	118

Table 7. Details of the sites on *Ceriagrion tenellum* where *Leptus killingtoni* were attached on first capture and on all recaptures.

	Head	Eyes	Pro-notum	Thorax dorsal	Thorax ventral	Abdomen	Femur	Tibia	Tarsus	Wings	Total
First capture	21	25	19	66	126	100	79	32	23	7	498
All recaptures	17	17	11	22	89	69	61	20	1	3	310
Total	**38**	**42**	**30**	**88**	**215**	**169**	**140**	**52**	**24**	**10**	**808**

thorax, 65.6% were on its ventral surface (Table 7, Plate 1).

Twenty eight *L. killingtoni* were observed on 17 individual damselflies in the same position as at the previous capture. Nine of these damselflies were recaptured the next day with at least one mite in the same position as the day before. The other eight were recaptured over a longer period of time (up to 16 days) with at least one mite in the same position as when first caught. The mites were not marked so it is impossible to tell whether the same mites were recorded on recapturing an individual *C. tenellum.* One *L. killingtoni* recorded below the thorax had dropped off on recapture later the same day. Whilst *C. tenellum* were being handled only three *L. killingtoni* were observed moving around and four dropped off.

Discussion

This was a one-season study with generally poor weather and so conclusions drawn from the results may not be typical of the species or the mite load in general. Corbet (1999) warned against generalizing about behaviour from observations made at one place or during one season and also stated that the prevalence of mite parasitism in adult Odonata varies between years, populations, and individuals.

The cool, wet and windy weather during the study period made flying conditions unfavourable, with *Ceriagrion tenellum* often caught whilst sheltering in the tall, dense tussocks of *Molinia caerulea* and *Schoenus nigricans*. The weather conditions may have shortened the lifespan and reduced the abundance of both *C. tenellum* and *Leptus killingtoni*. Forbes & Baker (1991) noted that "fasting leading to death through starvation may occur regularly in nature as *Enallagma* damselflies do not fly or forage on rainy or cool days (personal observations)".

Larval *L. killingtoni* were also noted in the study area on other insects such as the Brown China-mark moth *Elophila nymphaeata*, a beetle and several
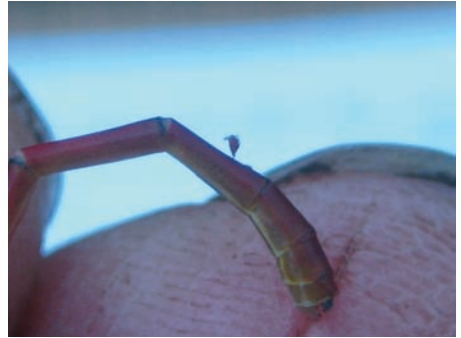
Plate 1. *Leptus killingtoni* on *Ceriagrion tenellum* (A) general view showing *L. killingtoni* on the tarsi of *C. tenellum*, (B) *L. killingtoni* on the bases of the legs of *C. tenellum*, (C) anterior end of *C. tenellum* showing mites on its legs, (D) *L. killingtoni* 'standing on its head' on the abdomen of *C. tenellum*. Photographs (A) by Ian Ward, (B) by Pete Adey.

grasshoppers, as well as on other Odonata species (Large Red Damselfly *Pyrrhosoma nymphula*, Keeled Skimmer *Orthetrum coerulescens* and Southern Damselfly *Coenagrion mercuriale*); also on the spider *Tetragnatha extensa*. This wide range of hosts suggests that L. *killingtoni* is a generalist. However, it should be noted that as Kerry & Baker (2012) stated "it is not yet possible to say with certainty that *L. killingtoni* is parasitic".

Despite similar numbers of the two female forms being marked (95 *melanogastrum* and 90 *typica*), *melanogastrum* were recaptured nearly twice as often as *typica* and lived, on average, four days longer. However, both forms had similar numbers of *L. killingtoni*. Further research is required for reasons why *melanogastrum* was recaptured almost twice as often as *typica,* given a similar number marked initially.

Prevalence of *Leptus killingtoni*

Habitat condition, population size of both parasite and host and weather conditions can all affect the interaction between the two species. In the present study a higher proportion of mature females (48.6%) than males (36.1%) carried mites on first capture. Although the overall prevalence figure of 40.2% was higher than in 2011 (32%) during the pilot study, the figures are comparable to those given by Lorenzo-Carballa *et al.* (2011) of a maximum prevalence of 41% on *Ischnura hastata* and 35% on *I. pumilio* from the island of Pico in the Azores. The paper by Lorenzo-Carballa *et al.* (2011) compared prevalence between different ponds on the island but *L. killingtoni* was not recorded at all of the ponds studied.   However, the proportions recorded in the present study and those of Lorenzo-Carballa *et al.* (2011) are much higher than the figure given for *L. killingtoni* on *C. tenellum* (8.3%) by Killington & Bathe (1946) from two sites in Dorset (Table 8), perhaps as a result of their small sample size recorded on *C. tenellum* (21 compared to 498 in the present study). They did, however, record a total of 170 mites on 726 individuals of eight different Odonata species.

Leptus killingtoni and paired **Ceriagrion tenellum**

There was no significant difference between the infestation of unpaired males and females, indicating that *L. killingtoni* has no preference and is an opportunist, climbing on any available host. However, paired females were more likely to be infested with *L. killingtoni* than unpaired females and males (whether paired or not). The reason for this has not been ascertained from this study but may be due to *L. killingtoni* crawling onto mating females from the vegetation, moving from males to females during mating or be more easily groomed from one sex than the other when the damselfly is part of a pair. Baker *et al.* (2008) recorded a similar sex bias, with mature female *Coenagrion puella* carrying more *Arrenurus*

Table 8. Comparison of the prevalence of *Leptus killingtoni* between the present study and that of Killington & Bathe (1946).

|	Males			Females		
	Number caught	With *L. killingtoni*	Prevalence	Number caught	With *L. killingtoni*	Prevalence
Present study	382	138	36.1%	185	90	48.6%
Killington & Bathe (1946)	171	11	6.4%	47	7	14.9%

mites than mature males. However, *Arrenurus* mites have a different life cycle to that of the terrestrial mite *L. killingtoni*, the larvae of the former needing to return to water to complete their life cycle. A female bias for *Arrenurus* spp. may help achieve this, as the mites can drop off into water when the female is ovipositing.

Location of *Leptus killingtoni*

Leptus killingtoni were recorded most often from areas more difficult to groom, with 25.3% recorded on the ventral surface of the thorax (and especially between the legs), 20.1% on the abdomen and 15.9% on the femur (Table 7). These figures were in broad agreement with those of Killington & Bathe (1946) for *L. killingtoni* on *C. tenellum* (Figure 2). They recorded more precisely where each mite was located (mesosternum, metasternum, coxa, metapleuron just below wing, etc.). Lorenzo-Carballa *et al.*, (2011) were studying a different host (the asexually reproducing *Ischnura hastata*)*,* so the attachment site figures are not directly comparable with those of *C. tenellum*. The difference in lifestyle between the two damselfly species may also affect the numbers of larval *L. killingtoni*.

Baker & Seldon (1997), Southcott (1992) and Norton *et al.* (1988) concluded that *Leptus* larval mites prefer areas of heavily sclerotized integument for attachment sites but Abro (1988) demonstrated that they will also attach to weakly sclerotized areas. The current study indicates that *L. killingtoni* does not show a preference, being found on both heavily and weakly sclerotized areas of
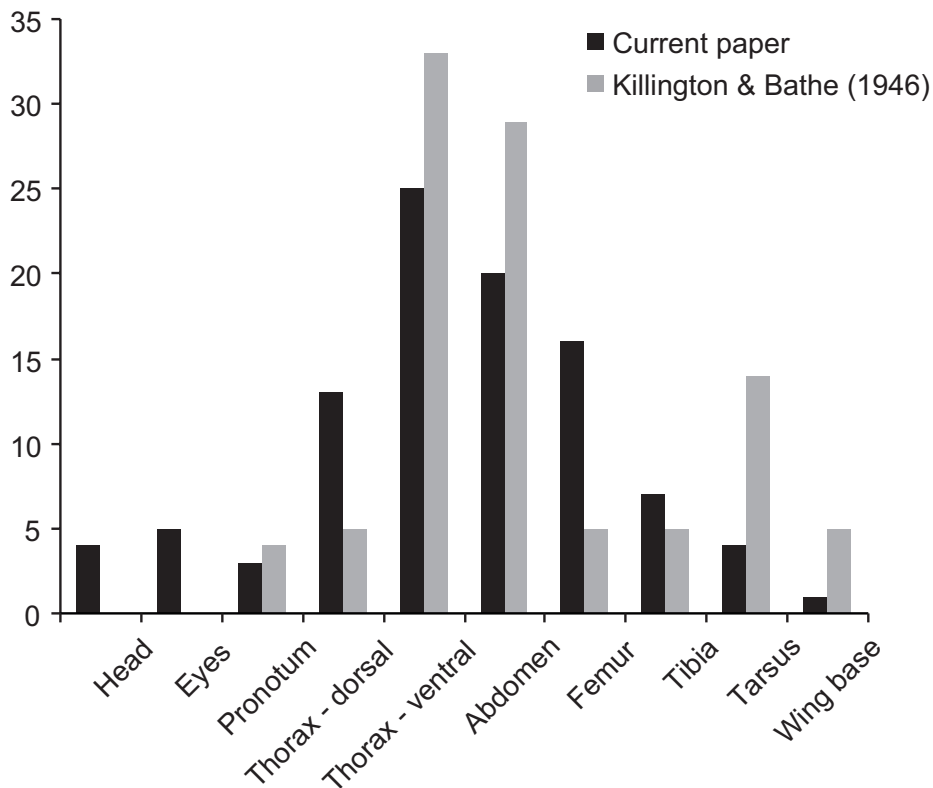
Figure 2. Percentage of *Leptus killingtoni* recorded at different locations on *Ceriagrion tenellum*, comparing data on first captures in the current work (n=498) to those of Killington & Bathe (1946) (n= 21).

its host, for example on the abdominal segments, on the junction between the segments and on both the ventral and dorsal surfaces of the thorax, as well as on the eyes.

Killington & Bathe (1946) commented on the firmness of attachment of *Leptus* larval mites and noted that, in most cases, they remained fastened to the host for considerable periods, including passage from the field to the laboratory and subsequent handling, although individuals occasionally dropped off during capture. In contrast, Lorenzo-Carballa *et al.* (2011) observed that *L. killingtoni* are easily detached from the host when captured. This study observed that 99.5% of *L. killingtoni* (804) remained on the hosts and only four were noted as detaching on handling. However, some may have dropped off and hence were not recorded. Three *L. killingtoni* were observed moving around on the hosts but

the majority appeared to be attached. Nine individuals were recaptured on the next day with *L. killingtoni* in the same position as on the previous day. Probably *L. killingtoni* do not attach to feed for long; also damselflies can groom them from more accessible places. Further investigation should focus on whether the mites are actually attached and feeding or not. This could be done by observing if they are moving and whether their jaws are embedded; also noting if they are attached in sclerotised or non-sclerotised regions.   This study recorded the general location in which the mites were seen and not whether they were attached, although many were observed 'standing on their heads' embedded into the damselflies (Plate 1D).

In the current study, considerable size differences were noted between individual *L. killingtoni*. The larger individuals could have fed and therefore have been engorged. On one occasion a male *C. tenellum* with a large *L. killingtoni* present on the ventral surface of the thorax was recaptured later and the mite had dropped off. Baker *et al.* (2008) recorded similar size differences between *Arrenurus* mites attached to *Coenagrion puella* and thought that this could reflect the period of time they had been attached to the host. It was thought that the larger specimens were feeding or had fed and were about to detach and that the smaller specimens had recently attached. Again further investigation is required.

In summary, this study has raised a number of questions, including:
- Why should the female *melanogastrum* form be recaptured nearly twice as often as the *typica* form?
- Why are more paired females infested than males (paired or unpaired) or unpaired females?
- Both this study and that of Killington & Bathe (1946) found *L. killingtoni* on wet heathland or mire sites. Has *L. killingtoni* been recorded on other habitats in Great Britain?
- Do individual mites remain firmly attached or do they frequently change sites?
- How long do mites remain attached to the host?
- Are the mites parasitic on their hosts?

Acknowledgements

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Some observations on the effect of temperature on dragonfly recording

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Summary

The British Trust for Ornithology added odonates to the species that contributors are asked to record from 2011. Records for the first two years of dragonfly records from this scheme have been analysed and indicate a marked difference in observations in the spring between 2011 and 2012. Spring 2011 was warmer than the recent average and noticeably warmer than in 2012 and dragonflies were recorded earlier in numbers in 2011 than in 2012. Based on a comparison of the records and the average weekly temperatures a correction factor is proposed to account for reduced dragonfly activity when temperatures are lower and it is suggested that this can explain some fluctuations in the raw data. It is also noted that the reduction in records from their peak can be described by a daily survival rate approach.

Introduction

In 2011 the British Trust for Ornithology (BTO) added the option to record Odonata to their Garden BirdWatch scheme (BTO, 2013). Participants record the species they see each week, thereby enabling changes throughout the year and from year to year to be followed. BTO have provided access to their dragonfly data for 2011 and 2012, allowing the data to be analysed. The records are useful because they have been submitted using a reasonably consistent recording method.

The Garden BirdWatch Records

In total 13,205 records of Odonata were submitted over the two years, 6,798 in 2011 and 6,407 in 2012. Although 2012 showed a significant reduction compared with 2011 (P<0.001 (χ^2 = 11.58), the totals hide specific differences between the two years. In 2011 there were 364 records before the end of April and a further 2,104 before the end of May. In 2012 there were only 44 records before the end of April and a further 943 by the end of May. These differences

are highly significant for both April (P<0.001, χ^2 = 251) and May (P<0.001, χ^2 = 442). In contrast, records from June onwards were higher in 2012, with 5,418 records against 4,628 in 2011, again a highly significant difference (P<0.001, χ^2 = 62).   Records were received for 34 species in total, 32 in 2011 and 29 in 2012, with 27 of the species being seen in both years. Four species accounted for over 1,000 records each over the two years, 11 between 100 and 999 records and 13 fewer than 10 records. Since the records consist of basic data without validation or further details, the value of the records for rare and scarce species is rather limited.   Records are at the level of a 1km grid square, with records received from 1,300 such squares over the two years (908 in 2011 and 894 in 2012, with 506 of these reporting in both years). It should be noted that the Garden BirdWatch reporting period is a week which starts on a Sunday. The dates for each week number used in this paper thus vary between the two years, being two days later in 2012 because it was a leap year.

Differences between 2011 and 2012

Figures from the Met Office (MetOffice, 2013) indicate that mean UK temperatures in 2011 were above the 30 year average (for 1971 – 2000) by 3.7°C in April and 1.0°C in May and the average Spring temperature (March to May) was the warmest since 1910. In contrast, mean UK temperatures in 2012 were 1.1°C lower than the 30 year average (1981 – 2010) in April and only 0.1°C above the average in May.

Temperatures through the summer were similar in both years, although it was warmer in late September/early October in 2011 than in 2012. The fact that there were more records in the summer period in 2012 suggests that recording effort in 2012 was a little higher than in 2011 and suggests that the additional
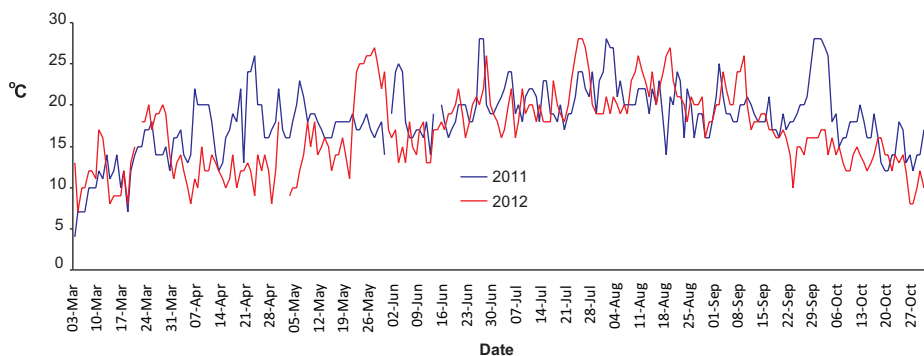
Fig. 1. Maximum daily temperatures recorded at Brize Norton, Oxfordshire in 2011 and 2012.

records in the Spring were even more significant. Temperatures followed the same pattern across the country although the absolute levels did vary. The daily maximum temperatures for Brize Norton (WeatherOnline, 2013) in Oxfordshire are shown (Fig. 1) but are representative for the bulk of the Garden BirdWatch records which tend to have a bias towards South–east England.

There was also a striking difference between the temporal distribution of records for species in which at least a high proportion of the population emerges in spring, as substantially more records were received from March to the end of May in 2011 than in 2012. The first period of high temperature in 2012 occurred at the end of May.

This difference is illustrated by the records for The Large Red Damselfly *Pyrrhosoma nymphula*, the species for which the largest number of records was submitted. This species has a highly synchronised emergence and is classified as a 'Spring' or Type 1 species (Corbet, 1954; Corbet & Brooks, 2008). The total number of records in 2011 for *P. nymphula* was significantly higher than
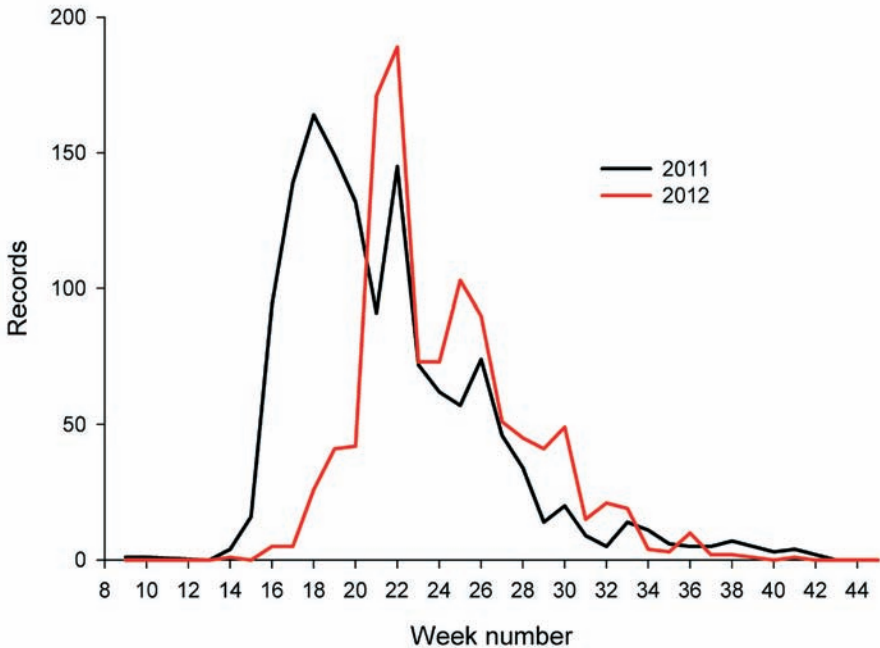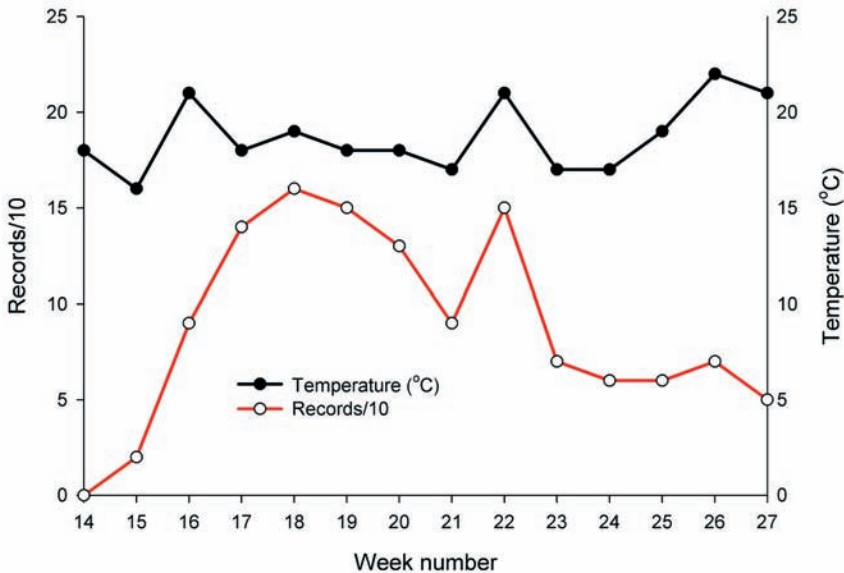

Fig. 2. Garden BirdWatch records for *Pyrrhosoma nymphula* in 2011 and 2012.
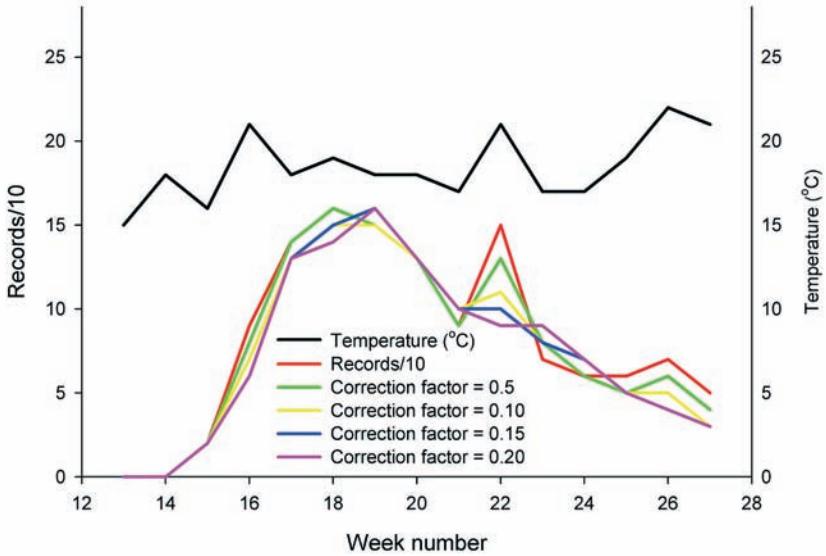
Fig. 3. Actual number of *Pyrrhosoma nymphula* records compared with the average peak daily temperature at Brize Norton, Oxfordshire in 2011 each week up to week 27. Note that, on the graph, the number of records has been divided by 10.

in 2012 (1,392 against 1,083; P<0.001, χ^2 = 38.58). The extra records in 2011 came from the early period (late April – mid May) (Fig. 2). There is no evidence that, when cooler weather delayed emergence in 2012, larger numbers then emerged or emergence continued for longer than in the previous year (Fig. 2). It should be noted that the records are based on presence and not abundance at a site. However, if numbers were higher one might expect them to occur at more sites and to be more readily detected at sites with a small population. Other species with a significant level of spring emergence showed a similar effect between the two years and summer emerging species also showed a greater tendency for earlier records in 2011 than in 2012.

The effect of temperature on records

Analysis of the records suggests that there is a correlation between the temperature during the recording period and the number of records. This can be illustrated by the pattern for *P. nymphula* for 2011 (Fig. 3). Here the increase in records in weeks 22 and 26 in 2011 coincides with generally higher temperatures. It is of course possible that the higher temperatures caused fresh emergence to take place but as a sole explanation this seems unlikely

Fig. 4. Actual number of *Pyrrhosoma nymphula* records up to week 27 with different temperature correction factors applied, compared with the average peak daily temperature at Brize Norton, Oxfordshire each week in 2011. Note that, on the graph, the number of records has been divided by 10.

as the increase in week 22 was substantial when the trend in numbers is clearly downwards and the temperature in the preceding weeks while not hot was also not cold. Dixon & Gennard (2010) reported that temperature had a significant effect on the level of dragonfly flight activity and thus it is likely that temperature will have an impact on the number being seen, primarily through increased activity as temperatures increase but also possibly, in the case of this dataset, with increased observer activity combined with an element of additional emergence. The records were examined to see if a correction factor could be applied to take account of the temperature in the recording week. A linear relationship is unlikely to fit because, as the temperature rises, the proportion of individuals that are active will tend towards a maximum. Similarly, as the temperature falls, activity will tend towards zero. A relationship described by the equation $N_a = N \times (18-T)^{(1+\delta)}$ where N is the number of records, T is the average weekly peak temperature in °C, δ is an adjustment factor and N_a is the adjusted number of records, is suggested as likely to reflect the probable changes. A base temperature of 18°C was selected as a rough average so that N_a is the predicted number of records at that temperature. A correction factor (δ) varying from 0.5 to 2.0 was applied to the records for *P.nymphula* (Fig 4.)
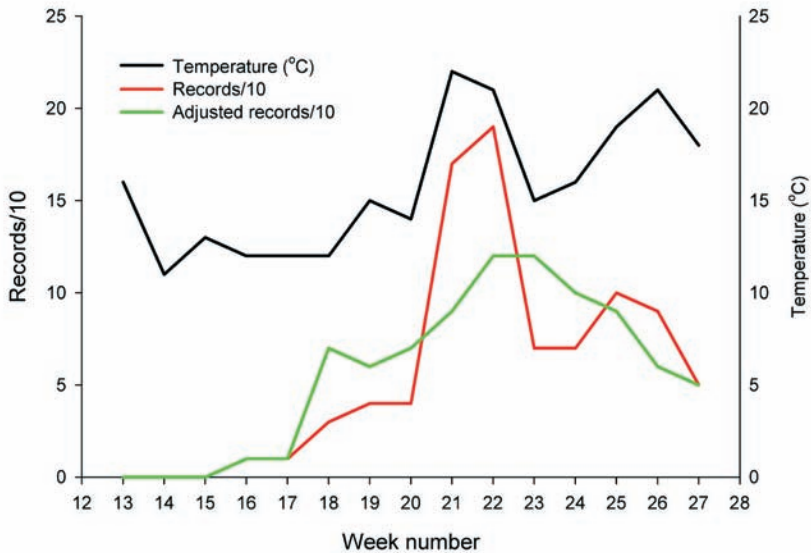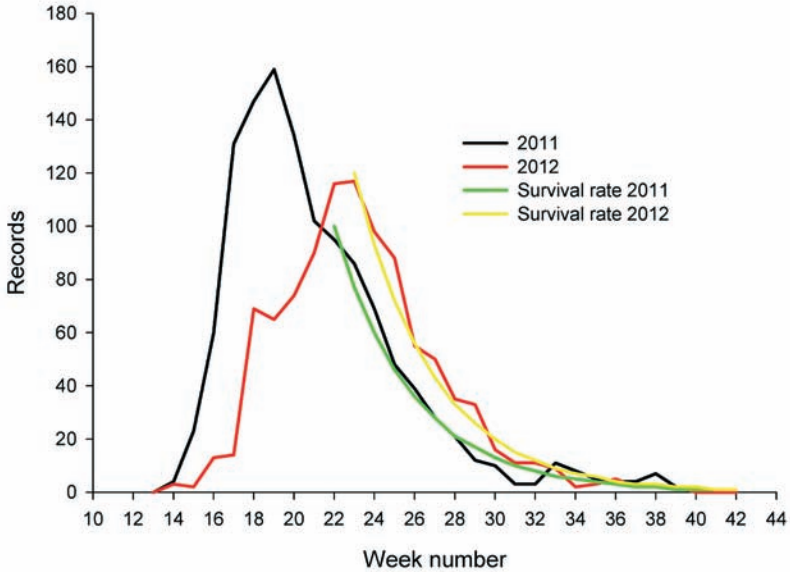
Fig. 5. Number of *Pyrrhosoma nymphula* records for 2012 up to week 27, both actual records and with a temperature correction factor of 0.17 applied. Note that, on the graph, the number of records has been divided by 10.

The value for δ which produces the best fit in smoothing the peaks at weeks 22 and 26 is between 0.15 and 0.2 and hence a value of 0.17 was selected for further analysis. Note that this means that the adjustment is +/-17% of the total at a particular temperature for a change of temperature of 1oC. The same correction factor was also applied to the 2012 records (Fig. 5). Application of the correction factor again smoothes the curve, suggesting that emergence from week 18 was higher than the base records might suggest because the low temperatures led to under-recording compared to the hot spell at the end of May.

Comparing the two years it can be seen that the peak in terms of records occurred earlier in 2011. The flight season was later in 2012 but the extension to the season is less than the delay at the start. This effect can be seen whether the number of records are corrected for temperature or not, but is clearer with temperature correction (Fig. 6).

Corbet (1952) published data on the survival rate of *P. nymphula* and concluded that, for adults surviving the maturation period (which he calculated to be 15
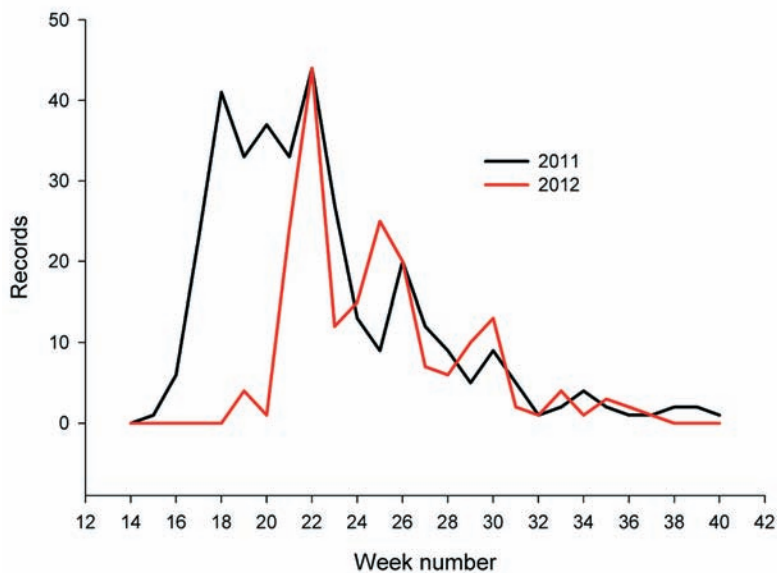
Fig. 6. Number of *Pyrrhosoma nymphula* records for 2011 and 2012 over the whole season with a temperature correction factor of 0.17 applied, showing that the decline in numbers in both years equates to a presumed "survival rate" of 96.4% per day.

days), the average total adult lifespan was 21.7 days. He estimated an average daily survival rate of 85%, falling from 90% at the start of the season to below 85% at the end. Bennett & Mill (1995) calculated that males take an average of 12.6 days to mature; females 15.0. Their mean reproductive lifespan (after maturation) was 6.8 and 6.6 days for males and females respectively, giving mean total lifespans of 19.4 and 21.6 days respectively for those individuals that survived the maturation period. The estimated daily survival rate for adults (from emergence) was 88.6% for males and 89.4% for females for those that survived the maturation period (not significantly different) (Bennett & Mill, 1995).

The best fit for the decline in number of records from the current dataset equates to a "survival rate" of 96.4% and this seems to fit for both years (Fig. 6). It should be noted that this dataset records occurrence rather than numbers. Numbers at a site may decline but it will still be recorded until no insects are seen. The "survival rate" calculated from this data set will therefore depend to some extent on the spread of population sizes and may tend to overstate the survival rate of individuals.

An attempt was made to see if there was a variation in the pattern of records
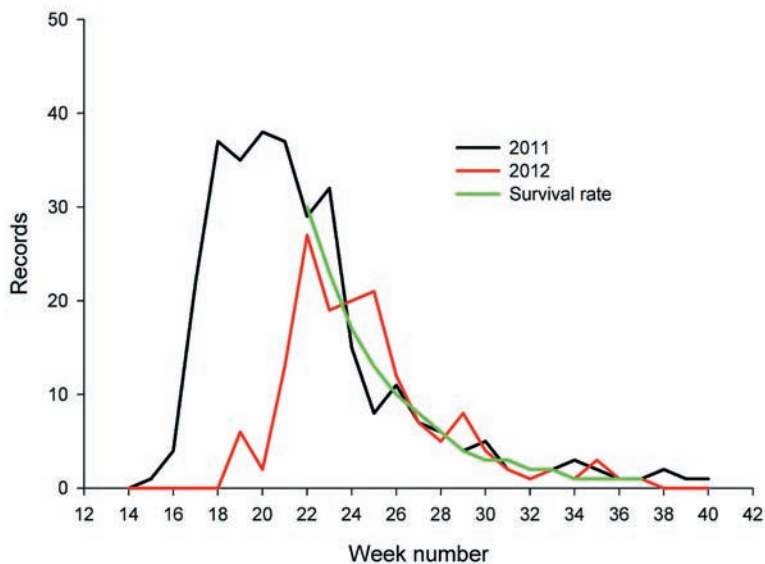
Fig. 7. Number of *Libellula depressa* records for 2011 and 2012 over the whole season. (A) actual records; (B) with a temperature correction factor of 0.17 applied, showing that the decline in numbers in both years equates to a presumed "survival rate" of 96.2% per day.

A

B

Fig. 8. Number of *Ischnura elegans* records for 2011 and 2012 over the whole season. (A) actual records, (B) with a temperature correction factor of 0.17 applied.

with latitude. This is not easy because there were relatively few records from Northern England and from Scotland. The results were not very conclusive with either no shift with latitude or a very slight tendency for records to build later and possibly to also decline more rapidly in more northerly latitudes.
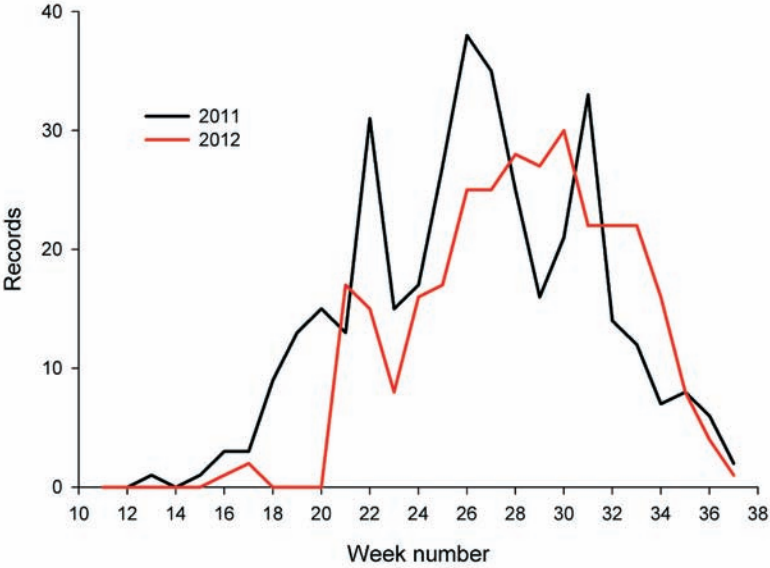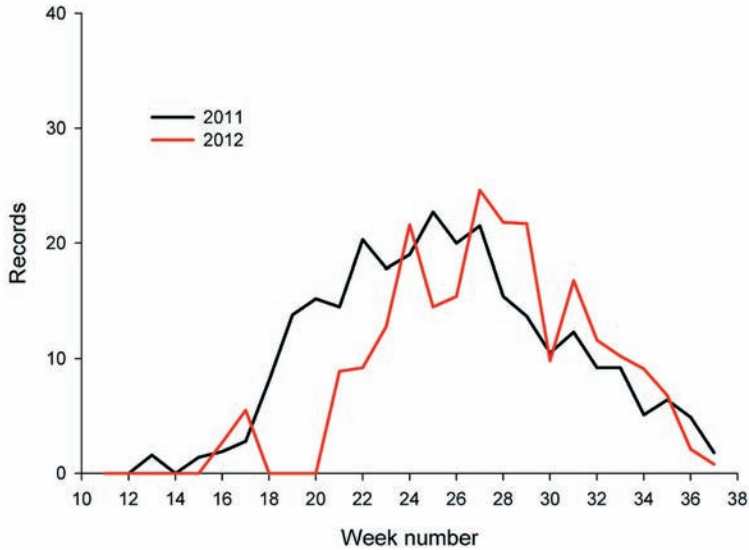
The Broad-bodied Chaser *Libellula depressa* was the only other spring emerging species (Type 1 species) recorded in sufficient numbers to allow analysis. The records for this species are even more striking. Emergence was significantly delayed in 2012 compared with 2011 but records started to decline at about the same time as in 2011 and the decline followed the same path in both years (Fig. 7A); this was even clearer when the records were corrected for temperature (Fig. 7B). The best fit "survival rate" for this decline is 96.2%, surprisingly similar to that for *P. nymphula*.

 The effect for 'Summer' or Type 2 species (Corbet, 1954; Corbet & Brooks, 2008) can be illustrated by the records for Blue-tailed Damselfly *Ischnura elegans*. (Fig. 8). Here once again there was an obvious delay in records building up in 2012 but from around week 23, when temperatures in the two years became broadly similar, the pattern of records was also very similar (Fig. 8A). Correcting for temperature once again smooths the curves and presents a clearer picture (Fig. 8B), although the same pattern can be seen in the uncorrected records.

Another Type 2 species which normally emerges in the summer is the Southern Hawker *Aeshna cyanea*. Emergence for this species normally occurs rather later than the period in which temperatures differed markedly between 2011 and 2012. The pattern in the two years was very similar, with possibly a small level of earlier emergence in 2011 but it was not particularly obvious. In 2012 during the peak of the season the numbers were slightly higher and this may reflect a slightly higher level of recording. These records are presented without temperature correction as the pattern is fairly clear without enhancement (Fig. 9). Indeed, temperatures over the main flight season were fairly stable and similar in the two years.

An assumed "survival rate" approach does not fit the pattern of either of these Type 2 species (*I. elegans* and *A. cyanea*) very well, as would be expected of species where emergence is spread over a period so that the population is a mix of ages. *A. cyanea*, which continues flying later than *I. elegans*, showed a more abrupt cut off to records but in both cases it is likely that the onset of autumn had an impact on the pattern of decline.
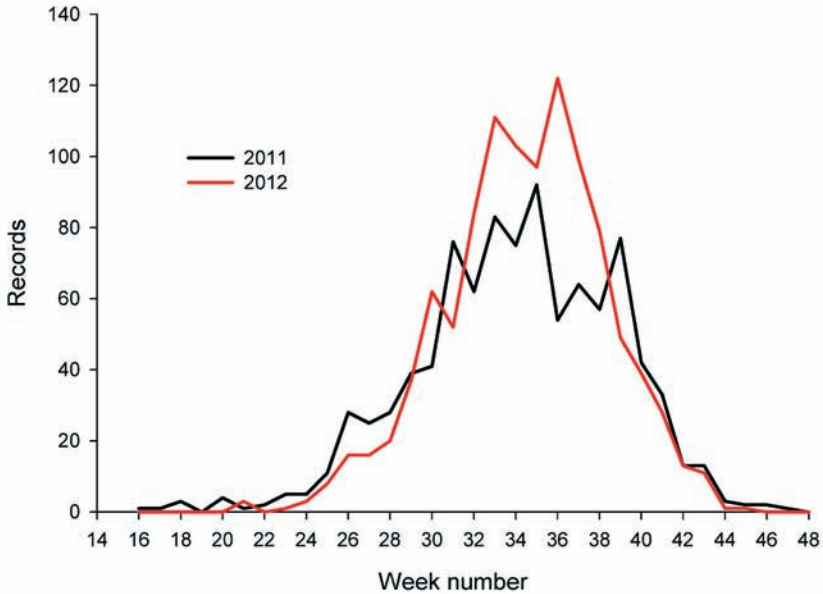
Fig. 9. Actual number of *Aeshna cyanea* records for 2011 and 2012 over the whole season.

Discussion

The BTO Garden BirdWatch scheme has the advantage of a large number of participants gathering records in a fairly consistent way. It does not have the rigour of a structured scientific study but such a study would be unable to provide the same scope or volume of data. There are clearly uncertainties which are intrinsic to schemes like Garden BirdWatch but the information they provide is interesting and useful. In some cases it identifies real data and in others it flags up possibilities which more structured studies can investigate in more detail.

It seems to be clear that the warm period in April 2011 had a marked impact on the emergence of those dragonflies and damselflies which emerge either wholly or partially in spring. The regular reporting nature of the scheme shows the effect more clearly than simply recording first emergence, although records of first emergence also showed a significant difference between 2011 and 2012 (Tyrrell 2012). In the warm weather of 2011 emergence started earlier and records built more quickly than in the cooler spring of 2012. The data indicated that the numbers emerging early in 2011 were a net gain to the population reaching maturity compared with 2012 and not simply a shift in the emergence

period. In *Pyrrhosoma nymphula* the decline in population levels was slightly later in 2012 but in *Libellula depressa* the decline in population occurred at the same time in both years, so that the flight season was much shorter in 2012. It seems that there is some factor, possibly day length, that acts as an end point for emergence in Type 1 life cycle species and, if the larvae have not emerged by this stage, they are unlikely to do so. It is interesting to consider what happens to them. Do the larvae continue to develop and then enter diapause to emerge the following year or do they die off. Another possibility is that the larvae die because the water (or air temperature) does not warm when they expect it to in spring and they succumb before being able to emerge or even before they reach the last instar. This may become an interesting issue as our weather seems to become more erratic. It is important to note that the temperature in spring 2011 was an exception. The temperature in 2012, although slightly below average, was much more typical of recent years.

The fact that the decline in records for the two Type 1 life cycle species considered seems to follow a curve dictated by a "survival rate" is interesting and to an extent is what might be expected from the Type 1 designation. Whether it has any particular relevance is uncertain, particularly as it is measuring presence/absence at sites rather than actual numbers of insects at a site.

The use of a correction factor to adjust the number of records for the effect of temperature during the recording period is speculative. The fact that activity levels vary with temperature has been demonstrated by other studies (Hilfert-Rüppell, 1998.) It is therefore reasonable to suppose that the level of dragonfly recording in the BTO Garden BirdWatch scheme will be affected by the temperature in each recording period. The method adopted seems to have some validity since it appears to work both between species and years but, if it is valid, it applies only to the specific circumstances of this scheme. In this case the temperature is an average of the daily maximum temperature across a full week. It does not take account of fluctuations in temperature across the country. Nonetheless, adjusting recorded numbers for the temperature might be an approach to consider when analysing records from other schemes and possibly ambient temperature should become something that is requested as part of any recording scheme.

Acknowledgements

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Web Sites

BTO 2013. Garden Birdwatch http://www.bto.org/volunteer-surveys/gbw

MetOffice. 2013. Overall monthly temperature compared to 30-year averages. http://www.metoffice.gov.uk/climate/uk/

WeatherOnline 2013, http://wwwweatheronline.co.uk/weather/ maps/city?LANG=en&UP=0&WMO=03649&CONT=ukuk&NOREGION=0&CEL=C&LEVEL=150&ART=MAX&R=150

Further studies on the Odonata from Bosnia & Herzegovina and their mite parasites.

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Summary

A brief review of the present knowledge of the Odonata from Bosnia and Herzegovina is followed by further work on their mite parasites; in particular their identification, distribution and host records. A total of 301 mites were mounted, counted and identified, most of them to species. *Arrenurus bicuspidator*, *A. bruzelii*, *A. cuspidator*, *A. cuspidifer*, *A. maculator* and *A. papillator* were identified on 13 odonate host species, including three Anisoptera: Norfolk Hawker *Aeshna isosceles* (Müller, 1767), Yellow-winged Darter *Sympetrum flaveolum* (Linnaeus, 1758) and Emperor Dragonfly *Anax imperator* Leach, 1815. The Zygoptera were the Scarce Blue-tailed Damselfly *Ischnura pumilio* (Charpentier, 1825), Blue-tailed Damselfly *Ischnura elegans* (Vander Linden, 1820), Azure Damselfly *Coenagrion puella* (Linnaeus, 1758), Variable Damselfly Coenagrion *pulchellum* (Vander Linden, 1825), Dainty Damselfly *Coenagrion scitulum* (Rambur, 1842), Large Red Damselfly *Pyrrhosoma nymphula* (Sulzer, 1776), Common Blue Damselfly *Enallagma cyathigerum* (Charpentier, 1840), Red-eyed Damselfly *Erythromma najas* (Hansemann, 1823), Scarce Emerald Damselfly *Lestes dryas* Kirby, 1890 and White-legged Damselfly *Platycnemis pennipes* (Pallas, 1771). Size measurements indicate that larval mites of the same species are much larger on anisopterans than on zygopterans and reasons for this are discussed.

Introduction

Bosnia & Herzegovina, situated in the southeastern part of Europe and part of the former Yugoslavia, became independent in 1992. It is a country dominated by mountains, forming the largest part of the Dinaric Alps, and has borders with Croatia to the west and north and Serbia and Montenegro to the east and a small part of the Adriatic coast. According to Dijkstra & Lewington (2006) and Kulijer *et al.* (2013) Bosnia & Herzegovina is very diverse in terms of dragonfly

habitats.

The oldest dragonfly data from the country originate from 1888 and are found in the entomological collection of the National Museum of Bosnia and Herzegovina in Sarajevo (Kulijer *et al.*, 2013). This is one of the oldest dragonfly collections in the Balkans and contains important historical records from the region (Kulijer & Marinov, 2010, Kulijer & Boudot, 2013). Adamović (1948) presented records of the specimens deposited in this collection originating from the territory of the former Yugoslavia, with data on 45 species from Bosnia and Herzegovina. This paper remained the most significant source of information on the dragonfly fauna of Bosnia and Herzegovina for a long time.

Recently, dragonfly research in the country has been intensified and much new data has become available. Several authors have published papers with new records (Bedjanić, 2011, Jović *et al.*, 2010, Kulijer, 2012, Kulijer *et al.*, 2012b). Based on all existing records and several thousand new ones, Kulijer *et al.* (2013) published a review of the dragonfly fauna of Bosnia and Herzegovina, giving data for 63 species.

Although comparatively little work has been carried out on dragonflies and damselflies in this area, historically two British workers were involved in the early work. An English naturalist, Malcolm Burr, collected Odonata material in the Balkans, including Bosnia, in 1898 and his specimens were identified by McLachlan (1898). Klapalek (1898) also reported on collections from this region in the same year.

With regard to mites ectoparasitic on dragonflies, Davids (1997) provided information on the species of mite found on odonates in Europe, Corbet (1999) has produced a detailed account of the biology of dragonflies, including a chapter on parasitism, and Zawal (2008) has produced an identification key with morphological characteristics of the larval stage of mites of the genus *Arrenurus*. Baker (2011) has recently reviewed parasitism in dragonflies and damselflies. In a previous paper by the present authors (Kulijer *et al.* 2012a) we described the odonate species found and their collection sites in Bosnia & Herzegovina. A map of the area was included as well as details of the specific locations where the dragonflies and damselflies were found. The load of parasitic mites and their sites on the host were also considered but the species of mite had not been determined at that time. The present paper records the identification of these parasitic mites, provides additional information on the Odonata from Bosnia & Herzegovina and discusses aspects of the host-parasite relationship, distribution and country records.

Materials and Methods

The dragonflies and damselflies were collected from 24 sites (Fig. 1) between May and August in 2011 and 2012 at a range of altitudes, several around 1400m or above, during the peak periods of adult activity. They were preserved in 70% ethanol, together with their mites. Mites were removed and mounted individually on slides in polyvinyl lacto-glycerol in order to identify them, each slide representing one host. Samples were used for mite identification purposes.
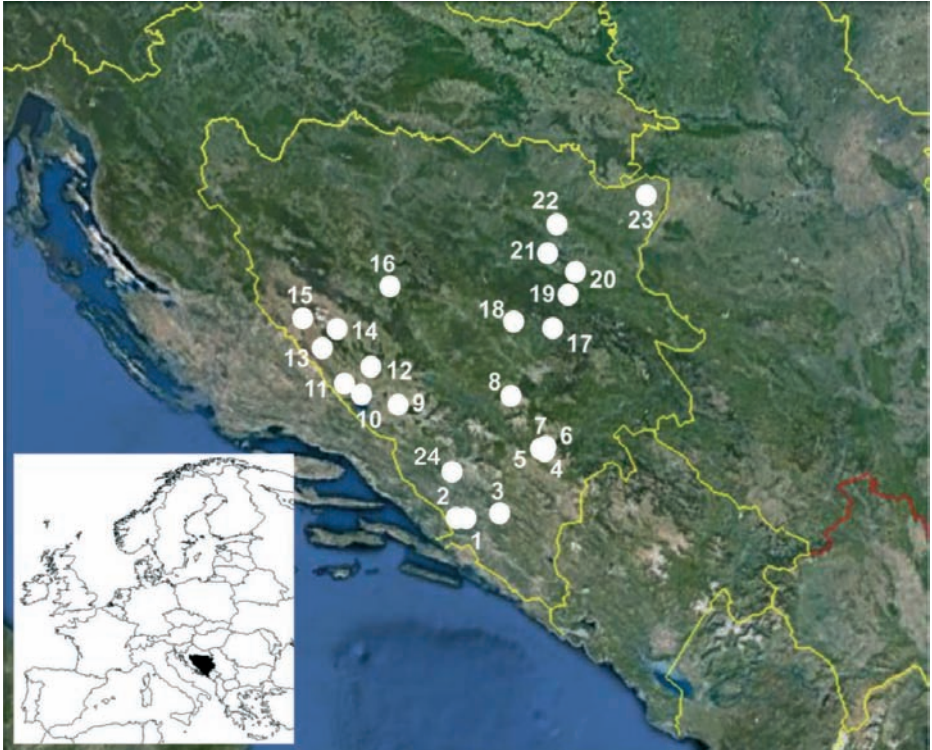
Fig. 1. Map of Bosnia and Herzegovina showing the locations of the sites sampled. 1, Stream at Londža, Hutovo blato; 2, Pond at Svitava; 3, Pond near Hodovo; 4, Ponds at Masna bara, Zelengora mountain; 5, Pond near Kladopolje; 6, Kladopoljsko lake; 7, Pond near Obalj, Kalinovik; 8, Lokvanjsko lake; 9, Canal near Mandino selo, Duvanjsko karst polje; 10, Pond at Ploča near Livno; 11, Pond near Orguz, Livanjsko karst polje; 12, Dragnić, Glamočko karst polje; 13, Oxbow near Vrbica, Livanjsko karst polje; 14, Ribnik stream, Glamočko karst polje; 15, Šatorsko lake; 16, Malo Plivsko lake; 17, Bakići near Olovo; 18, Haljinići ponds; 19, Stream near Stupari; 20, Bašigovci lake; 21, Pond near Prokosovići; 22, Tinja river; 23, Dašnica canal at Crnjelovo; 24, Govnuša, Mostarsko blato. Inset, location of Bosnia and Herzegovina. Site 24 is located at N43° 20'13" E17° 40' 28". For other site locations see Kulijer *et al.* (20122).

Further details of the sites where collections were made and other information on the Odonata found are given in Kulijer *et al.* (2012a).

Results

The following species of arrenurid mite larvae have been identified: *Arrenurus bicuspidator*, *A. bruzelli*, *A. cuspidator*, *A. cuspidifer*, *A. maculator* and *A. papillator*, together with *Hydryphantes octoporus*. The most common species was *A. cuspidator* (70%), followed by *A. bicuspidator* (11%) and *A. cuspidifer* (11%). Only one species (*A. cuspidifer*) was identified on the Anisoptera examined, although another species found on Emperor Dragonfly *Anax imperator* remains to be described and is listed at this stage as *Arrenurus* sp.1. Another unidentified species, *Arrenurus* sp.2, was found on the Azure Blue Damselfly *Coenagrion puella*. These two mite species, not previously described as larvae but not new species, await further work and descriptions.

Mites were found on 10 species of zygopteran and three species of anisopteran (Table 1). In some cases more than one mite species occurred on a host. Thus *A. bicuspidator* and *A. bruzelii* were found together on both the Common Blue Damselfly *Enallagma cyathigerum* and the Variable Damselfly *Coenagrion pulchellum*, while *A. maculator* and *A. cuspidator* were found together on a specimen of *C. puella*. A single specimen of a freshwater mite larva, from another family, the Hydryphantidae, *Hydryphantes octoporus*, was collected on the Blue-tailed Damselfly *Ischnura elegans*.

There were significant differences in the size of *A. cuspidifer* on the Yellow-veined Darter *Sympetrum flaveolum* (Anisoptera) compared to those found on the Zygoptera, with some very large specimens on the former (Table 2). Thus, the mean size of *A. cuspidifer* on the Dainty Damselfly *Coenagrion scitulum* was 422 µm (range 401-451 µm) and on the Scarce Blue-tailed Damselfly *Ischnura pumilio* it was 356µm (range 273-433 µm), whereas on *S. flaveolum* the mean size was 711 µm and there were large size differences between the mites found on this species, with a size range of 245-1383 µm.

The following are new records for mite species in Bosnia and Herzegovina, based on the larval stage parasitic on odonates.

Arrenuridae Thor, 1900

Arrenurus bicuspidator Berlese, 1885. Previously recorded from ponds in Montenegro, Bulgaria and Greece. Hosts: *E. cyathigerum* and *C. pulchellum*. New sites: Londža, Hutovo blato and Malo Plivsko lake.

Table 1. List of host Odonata parasitized by mites, collected from Bosnia & Herzegovina (including previous records from Kulijer *et al.*, 2012a). Continental English Vernacular names according to Dijkstra & Lewington, 2006).

	Vernacular Name (English)	
Zygoptera	UK	Continental Europe
Ischnura pumilio (Charpentier, 1825)	Scarce Blue-tailed Damselfly	Small Bluetail
Ischnura elegans (Vander Linden, 1820)	Blue-tailed Damselfly	Common Bluetail
Coenagrion puella (Linnaeus, 1758)	Azure Damselfly	Azure Bluet
Coenagrion pulchellum (Vander Linden, 1825)	Variable Damselfly	Variable Bluet
Coenagrion scitulum (Rambur, 1842)	Dainty Damselfly	Dainty Bluet
Pyrrhosoma nymphula (Sulzer, 1776)	Large Red Damselfly	Large Red Damselfly
Enallagma cyathigerum (Charpentier,1840)	Common Blue Damselfly	Common Bluet
Erythromma najas (Hansemann, 1823),	Red-eyed Damselfly	Large Redeye
Lestes dryas Kirby, 1890	Scarce Emerald Damselfly	Robust Spreadwing
Platycnemis pennipes (Pallas, 1771)	White-legged Damselfly	Blue Featherleg
Anisoptera		
Aeshna isosceles (Müller, 1767)	Norfolk Hawker	Green-eyed Hawker
Sympetrum flaveolum (Linnaeus, 1758)	Yellow-winged Darter	Yellow-winged Darter
Anax imperator Leach, 1815	Emperor Dragonfly	Blue Emperor

Table 2. Samples of the number of the mites *Arrenurus bicuspidator*, *A. cuspi*dator, *A. cuspidifer* and *A. papillator* and their mean size and size range from samples of Odonata.

Odonate species	n	Mean (µm)	Range (µm)
A. bicuspidator			
Enallagma cyathigerum	20	407	326-477
Coenagrion pulchellum	6	403	305-445
A. cuspidator			
Coenagrion puella	34	408	295-476
Pyrrhosoma nymphula	10	432	399-467
Ischnura pumilio	42	417	355-476
A. cuspidifer			
Coenagrion scitulum	3	422	401-451
Ischnura pumilio	9	356	273-433
Aeshna isosceles	2	412	403-420
Sympetrum flaveolum	13	711	245-1383
A. papillator			
Lestes dryas	14	390	292-451

Arrenurus bruzelii Koenike, 1885. Previously recorded from lakes and ponds in Macedonia, Bulgaria and Greece. Hosts: *E. cyathigerum* and *C. pulchellum*. New sites: Malo Plivsko lake.

Arrenurus cuspidator (Muller, 1776). Previously recorded from ponds and pools of running water in Serbia and Macedonia. Hosts: *E. cyathigerum*, *C.*

puella and *P. nymphula* (Large Red Damselfly). New sites: Stupari; Ribnik stream, Glamočko polje; Ploča pond, Livno; Bašigovci lake; Šatorsko lake; Haljinići ponds; Govnuša, Mostarsko blato and Škrka lake, Hutovo Blato.

Arrenurus cuspidifer Piersig, 1894. Previously recorded from ponds and pools of running water in Montenegro, Serbia, Macedonia and Bulgaria. Hosts: *C. scitulum*, *I. pumilio*, *A. isosceles* (Norfolk Hawker) and *S. flaveolum*. New sites: Svitava pond; pond near Kladopoljsko jezero, Orzug in Livanjsko polje; Vrbica in Livanjsko polje; Bakići near Olovo; Obalj village near Kalinovik; Šatorsko lake; Haljinići.

Arrenurus maculator (Muller, 1776). Previously recorded from ponds and lakes in Macedonia, Montenegro and Serbia. Host: *C. puella*. New site: Haljinići.

Arrenurus papillator (Muller, 1776. Previously recorded from ponds and canals in Bulgaria, Greece, Macedonia, Montenegro. Host: *L. dryas* (Scarce Emerald Damselfly). New site: Haljinići.

Hydryphantidae Piersig, 1896 - Subfamily Hydryphantinae Piersig, 1896

Hydryphantes (Polyhydryphantes) octoporus Koenike, 1896. Previously recorded from temporary and permanent stagnant water in Macedonia and Greece. Host *I. elegans*. New site: pond at Prokosovići.

Mites were also recorded on the White-legged Damselfly *Platycnemis pennipes* and the Red-eyed Damselfly *Erythromma najas* but were lost in transit and hence have not been identified.

Discussion.

All of the Arrenurid mites recorded here, *Arrenurus bicuspidator*, *A. bruzelii*, *A. cuspidator*, *A. cuspidifer*, *A. maculator* and *A. papillator* have been recorded previously as adults from the Balkans (Pešić *et. al*. 2010), including Bulgaria and Greece, and all except *A. papillator* from lakes in the Balkans (Baker *et. al*. 2008b); most have been recorded as larvae from Poland (Baker *et al*. 2007, 2008a). However, as far as we are aware, none have previously been identified from Bosnia & Herzegovina and certainly not as parasitic larvae on Odonata.

Davids (1997), correlating the work of previous authors, indicated *A. cuspidifer* on *Ischnura elegans*, *A. cuspidator* on *I. elegans*, *Coenagrion hastulatum* and *C. pulch*ellum, with *A. bruzelii* and *A. bicuspidator* on a wide range of odonate hosts.

It would appear that *Arrenurus* spp. are not host specific but rather opportunistic parasites with a wide odonate host range. However, Davids (1997) tabulates *A. papillator* as the only mite species found on all six species of *Sympetrum* that he lists. Zawal (unpublished observations) has found several mite species on the anisopterans *Anax imperator, Sympetrum flaveolum, S. vulgatum* (Vagrant Darter) and *S. sanguineum* (Ruddy Darter) *and Libellula quadrimaculata* (Four-spotted Chaser). It would therefore appear that *A. papillator*, although most commonly found on *Sympetrum* spp, may also be found on other Odonata. In the present study the only mite found on *Sympetrum flaveolum* was *A. cuspidifer*. More information is required for the Anisoptera before firm conclusions can be drawn about host specificity.

The single record for *Hydryphantes octoporus* is interesting. The genus *Hydryphantes* is normally associated with Diptera (Smith & Oliver, 1976) rather than Odonata but Zawal & Dyatlova (2010) have recorded it on *I. elegans* and *Erythromma najas* from South-western Ukraine and by Zawal & Therry (unpublished data) on *Coenagrion scitulum* from France . Given the current confirmation it appears that, although *Hydryphantes* is only rarely found on Odonata, it is not specific to one insect order. Larvae of *Georgella* sp. (Hydryphantidae) have been reported previously on zygopterans by Münchberg (1935, 1936) but the records were based on misidentified larvae, making it doubtful whether they belonged to the genus *Georgella* or, indeed, whether they were even aquatic mites (Tuzovskij, 2007).

The size measurements for *A. bicuspidator* and *A. cuspidator* on Zygoptera are comparable with the figures recorded previously by Baker *et al.* (2008a) but *A. cuspidifer* was not included in those measurements. Of the anisopterans listed here, all the mites sampled (n=15) were found to belong to *A. cuspidifer*. The differences in the size of individuals (Table 2) of the mite *A. cuspidifer* on damselflies and on the dragonfly *S. flaveolum*, where in the latter several are over 1,000µm in size, is interesting. Smith (1988) stated that enlargement is correlated with the time spent on the host and that larval *Arrenurus* spp. on Odonata could undergo an 80-90 fold increase in volume. On the other hand, reduced growth in multiple infestations indicates competition for food resources. It is suggested that mites on Anisoptera, some of which are well over 1mm long, spend more time on the host than those on Zygoptera and that this accounts for their larger size.

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A review of contact sensing during endophytic oviposition in Odonata

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Summary

This paper reviews the morphology and use of the endophytic ovipositor, with particular reference to the styli and their function in aiding the positioning of eggs. Differences in the structure of the styli between anisopteran and zygopteran odonates and between different species of aeshnid are reviewed. It is hypothesised that differences in the structure of the styli are related to differences in the complexity of the preferred oviposition substrate.

Introduction

Odonata oviposit in one of three ways (Corbet, 1999):

- •Exophytic oviposition, where eggs are laid by dipping the end of the abdomen in water, releasing a clutch, or where the eggs are flicked and stick to the surface of reeds or mud.
- •Epiphytic oviposition, where eggs are placed on the outside of plant material.
- •Endophytic oviposition where the eggs are inserted directly into the substrate, such as reeds, logs, etc.

The ovipositor of female Odonata varies in appearance depending on which of the three methods is used. In each case it is important that the female is able to sense when the ovipositor is in the correct position to lay the eggs.

The ovipositor in endophytic Odonata possesses three pairs of valves, V1, V2 & V3 (Fig. 1), the members of each pair being fused together. Two are used for cutting into the substrate (V1 & V2) and the third (V3) for protecting the cutting units. The third valve also bears a pair of styli.

Using scanning electron microscopy, Matushkina & Gorb (2002) and Matushkina (2008) showed the presence of fine setae (touch receptors) and campaniform
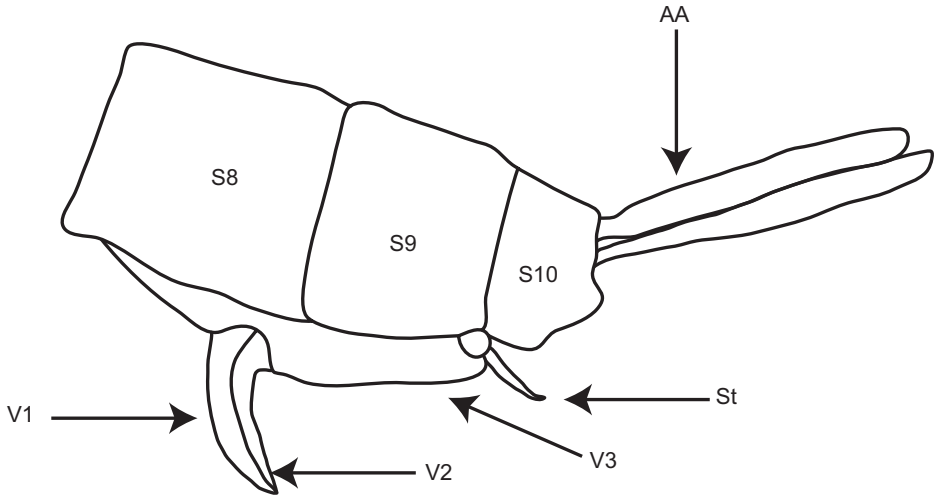
Figure 1. Morphology of the ovipositor of *Aeshna mixta.* AA, anal appendages; S8-S10, abdominal segments 8-10; St, stylus; V1, first cutting valve; V2, second cutting valve; V3, protective valve;

sensilla (stress detectors) on the surface of the valve, V3 and on the styli. In both species each stylus is covered with setae, including a group at its tip. In *Lestes sponsa* (Emerald Damselfly) there is a group of 15-20 campaniform sensilla located at the joint between V3 and each stylus (Matushkina & Gorb, 2002). In *Epiophlebia superstes* there is a group of campaniform sensilla on V3 and another on each stylus, both near the junction of V3 and the styli (Matushkina, 2008). They hypothesised that these mechanoreceptors (setae and campaniform sensilla) detect when the ovipositor is in contact with the substrate. When suitably located, valves V1 and V2 function to cut the substrate, allowing the insertion of an egg and preventing movement of the ovipositor during egg insertion (Matushkina & Gorb, 2002).

In order to test their hypothesis, Matushkina & Gorb (2002) removed styli from *L. sponsa* and tracked the location of eggs within the substrate. When both styli were present, the egg line showed no lateral displacement. When the left stylus was removed, the egg line veered to the right towards the remaining stylus and vice-versa. This work demonstrated that the stylus is involved in the accurate control of the egg line and positioning of the egg set in *L. sponsa.* When both styli were removed, the egg line appeared unaffected; however, the position of individual eggs was disturbed. This implies that the styli are important for accurate egg location but not that important for detecting the presence or absence of a suitable substrate, at least in *L. sponsa.* The presence of sensitive setae on the ovipositor valve, V3 must then determine the presence or absence of the

substrate. Similar work on other endophytic odonates, especially anisopterans, does not appear to have been undertaken.

Field Observations

Observations of ovipositing Odonata were made in the field and through studying hi-resolution digital photographs taken at the time. The styli are clearly visible on female odonates (Figs 2-6). All Odonata that possess these styli are classified as endophytic ovipositors. Analysis of the ovipositors of exophytic Odonata show an absence of the styli.

The ovipositors of four aeshnid odonates (*Brachytron pratense* (Hairy Dragonfly), *Aeshna mixta* (Migrant Hawker), *A. grandis* (Brown Hawker) and *A. cyanea* (Southern Hawker)) showed some significant differences in the shape and size of the styli (Figs 2-5). *Brachytron pratense* (Fig. 2) typically oviposits into dead and decaying plant material on the surface of the water (Brooks, 1999, Tyrrell, 2011), although it has been recorded ovipositing into dry logs by the side of ponds (Warne, 2011). Each stylus appears to consist of two parts with a thicker stem joining V3 and a finer filamentary structure at the distal end. *A. mixta* (Fig. 3) oviposits into live substrates but will also oviposit into dead material (Brooks, 1999). Its styli appear to have the same structure as those of *B. pratense*. The styli of *A. grandis* (Fig. 4) are markedly shorter and stubbier than those of the previous two species (*B. pratense and A. mixta*) but terminate in a similar filamentary structure. *A. grandis* typically oviposit into muddy areas on pond margins but will also use surface floating plant materials. *A. cyanea* (Fig. 5) possesses a stylus more similar in size to that of *B. pratense*.

Styli are also present on zygopteran odonates such as *Platycnemis pennipes* (White-legged Damselfly) (Fig. 6), *Calopteryx splendens* (Banded Demoiselle)*, C. virgo* (Beautiful Demoiselle)*, Pyrrhosoma nymphula* (Large Red Damselfly) and *Lestes sponsa* but none of these zygopterans show the same structure as in the anisopterans described above.

Discussion

The structure of the styli in aeshnid odonates varies between those species studied in this review. *A. grandis* has a short stylus, while those in *Brachytron pratense*, *A. mixta* and *A. cyanea* are longer. The styli in all four of these species appear to be in two parts, with a thicker stem joining valve V3 and a thinner terminal filament. Matushkina & Gorb (2002) have shown that the purpose of the styli is connected with the accurate positioning of eggs, rather than in detecting

A   B

Figure 2. (A) resting female *Brachytron pratense*, (B) enlarged view to show a stylus (arrow).

A   B

Figure 3. (A) ovipositing *Aeshna mixta*, (B) enlarged view to show a stylus in contact with the substrate (arrow).

A   B

Figure 4. (A) resting *Aeshna grandis*, (B) enlarged view to show a stylus (arrow).

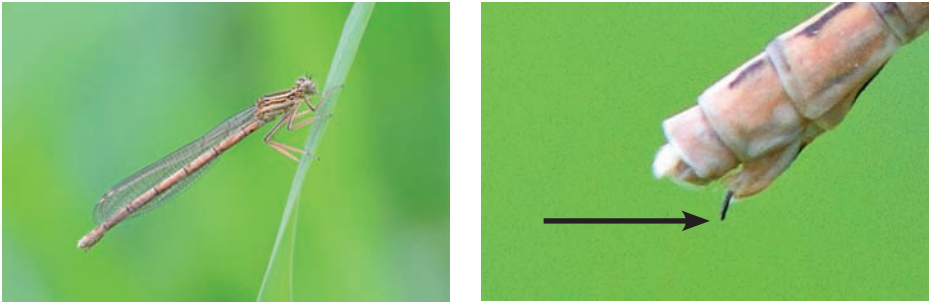A   B

Figure 5. (A) resting *Aeshna cyanea*, (B) enlarged view to show both styli (arrow).

A   B

Figure 6. (A) resting female *Platycnemis pennipes*, (B) enlarged view to show a stylus (arrow).

the presence of a substrate, so it is hypothesised that the filamentary styli of these aeshnids are suited to sensing the variety of surface structures, such as uneven surfaces of mud and logs compared to more uniform substrates such as live plant material. Observations of the ovipositing action of these four aeshnids suggest that, rather than inserting eggs in a linear manner, such as *L. sponsa*, eggs are inserted in an arc or circular pattern. Thus the styli may also be used to detect the presence of the substrate, unlike in *Lestes sponsa*. The styli of zygopteran odonates are more regular in structure and perhaps better suited to the choice of the more uniform, live plant material that these species prefer to oviposit into and in determining the linear pattern of egg deposition.

Conclusions

The styli of anisopteran and zygopteran odonates provide a mechanosensory device to precisely position eggs into the chosen substrate. In species that insert eggs linearly in a relatively uniform substrate, the styli appear uniform in structure. In those species that insert eggs typically into a variety of even and uneven substrates, in an arc pattern, the styli have a two part structure comprising a thicker basal stem and a finer terminal filament.

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