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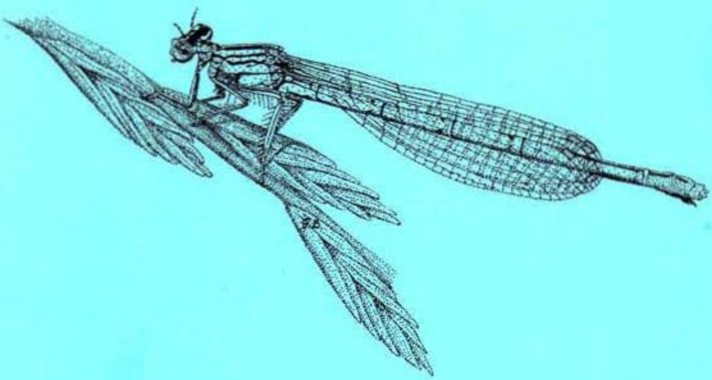

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Front cover illustration: White-legged Damselfly *Platycnemis pennipes* at Cowden Pound, Kent, 19 July 1997, by Gill Brook

In-flight cleaning behaviour by male Migrant Hawkers, *Aeshna mixta* Latreille

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Summary

This paper describes the use of the abdomen and legs as part of a sequence of cleaning behaviour performed by male Migrant Hawkers, *Aeshna mixta* Latreille, while flying.

Introduction

During late summer, males of *Aeshna mixta* spend much of their time at the breeding site, searching for females amongst stands of emergent vegetation. Females are known to oviposit endophytically in such areas and males have a high success rate at encountering them at this time (pers. obs.). To the observer the first indication of ovipositing females is often the sound of their wings brushing against plant stems as they oviposit.

Searching males will patrol the margins of breeding pools, frequently hovering near to the stands of emergent vegetation. They will fly into the stands, manoeuvring in very tight spaces between the plant stems. At peak flight times it is not uncommon to observe several ovipositing females and a number of searching males within prime areas of less than 25m^2 area (pers. obs.).

Most odonate cleaning behaviour has been described whilst individuals are either perched or at rest and is rarely reported in flight. Vertical up and down movements of the abdomen (abdomen bobbing) have been observed in a number of damselfly (zygopteran) families whilst perched (e.g. Consiglio, 1974; Naraoka, 1984). Various functions have been ascribed to abdomen bobbing in different species (see Corbet, 1999), including cleaning the wings in lestids (Loibl, 1958) and calopterygids (Heymer, 1972; Utzeri *et al.*, 1983, 1987). Abdomen bobbing in flight has been reported more rarely in anisopteran dragonflies (Kaiser, 1974; Utzeri & Raffi, 1983).

Field technique

Observations of cleaning behaviour have been carried out by the author over a number of years. In-flight searching and cleaning behaviour have been photographed using very short exposure times with a high speed Digital SLR camera. This has enabled rapid sequences of flight photographs to be made, so that field observations can be analysed later. This behaviour was studied particularly during the summers of 2004, 5 and 6, when several thousand flight photographs were made.

Observations

During search flights into emergent vegetation, males would often emerge with fragments of plants and gossamer from spiders webs attached to the wings and body. Photographs show this to be a frequent occurrence. After leaving the search area males continued to patrol but would undergo a three-stage sequence of cleaning motions whilst in flight. Firstly the wings would be cleaned, using the abdomen as a 'brush', a behaviour known as abdomen bobbing. Here the abdomen is used to clean the wings by curving upwards between the wings in a short series of undulating flight movements. This is invariably followed by the legs being used to clean the abdomen and then the legs cleaning each other.

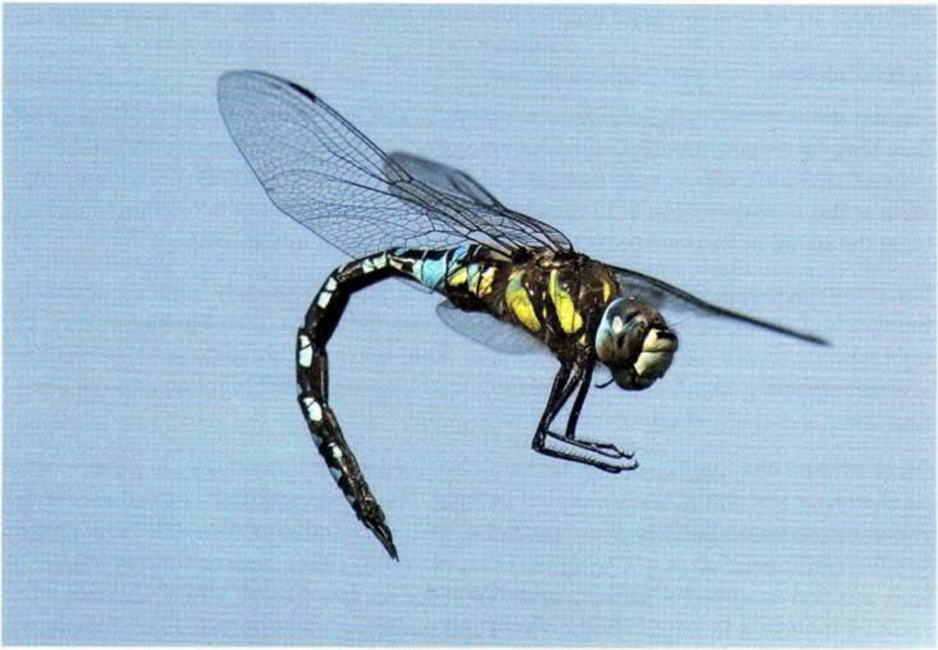

Plate 1. Male *Aeshna mixta* cleaning abdomen and legs. Note the front legs are folded behind the eyes.

The abdomen is cleaned by curving it downwards and forwards so that the tip points forward and comes into contact with the legs. The legs are then scraped along the abdomen to remove any particles or gossamer. Flight photographs show that the hind and mid pairs of legs are used for this and the front legs remain folded behind the eyes (Plate 1). This is then followed by the mid and hind legs cleaning each other by a series of brushing movements. The legs are then folded under the thorax and the male continues patrolling flight.

Discussion

In-flight cleaning occurs frequently in males of *A. mixta* and provides them with an effective mechanism for the removal of debris from the wings, abdomen and legs picked up from flying in stands of emergent vegetation during their search for females. Similar cleaning behaviour has also been observed by the author in males of *A. cyanea* and *Anax imperator*, although less frequently. Abdomen bobbing was recorded in a single male of *A. affinis*, a species that also often flies low around the bases of reeds and sedges, by Utzeri & Raffi (1983). Kaiser (1974) suggests that, in *A. cyanea*, all pairs of legs are used during abdomen cleaning. This may be in error, as at all times in the author's observations, the front legs are folded behind the head in the in-flight photographs taken during this study. Clearly modern digital photography has an increasing role to play in the study of dragonfly behaviour.

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Development and hatching of eggs of the Common Darter, *Sympetrum striolatum* (Charpentier)

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Summary

Eggs of *Sympetrum striolatum* (Charpentier) develop and hatch in less than two weeks. During this time they are protected by a gel-like mass that surrounds them. Differences in the process of hatching are described.

Introduction

Females of *Sympetrum striolatum* oviposit exophytically by hovering over a selected area of water. This is usually in tandem, where the male will take the lead role, but is sometimes alone (Ottolenghi, 1987). Eggs are laid in batches of varying number by repeated contact of the tip of the abdomen with the water. This is sufficient to break the surface film and ensure that the eggs quickly sink to the nearest substrate. Selected areas are typically where water overlays a darker substrate below (pers. obs.). This ensures that eggs are more likely to come into contact with suitable substrate for development.

The eggs are elliptical and have a sticky surface coating that adheres to the first substrate that they come into contact with as they sink. The eggs first appear pale cream in colour, darkening to orange within a few hours. Due to their small size it is difficult to study their development under natural conditions. A number of members of this genus are known to lay eggs in late summer and autumn and that these remain in a state of diapause before hatching the following spring (see Corbet, 1999). For example, in *S. danae* the period from oviposition to hatching has been recorded under field conditions as 217–239 days (Waringer, 1983). Egg development stopped around the autumnal equinox, diapause being terminated in mid March. However, a study by Ottolenghi (1987) on *S. striolatum* showed that, under laboratory conditions, eggs laid in September hatched after 10–15 days whereas those laid in late October took 88–104 days to hatch, i.e. in late January to early February. The latter often experienced conditions where the air temperature was below 0°C.

Material and methods

During September 2006 tandem pairs were regularly seen ovipositing at my garden pond in Silsoe, Bedfordshire. An ovipositing pair was captured on 10 September with a net and the female encouraged to shed eggs into a clear plastic container filled with approximately 12mm of pond water by simulating the tapping movement of the abdomen on water. To obtain sufficient eggs 4–5 taps were made and this yielded 345 eggs that promptly sank and adhered to the bottom of the container.

During the study period of two weeks the container was kept in a room with a north facing aspect with relatively stable temperature conditions of approximately 21°C during the day. Observations were made at frequent intervals during this time using a Leica M420 stereomicroscope at magnifications between 6.3× and 60×. Illumination was provided by a twin gooseneck fibre optic to eliminate any heating effect and also enable optimal positioning for semi backlighting to reveal the contents of each egg.

Observations

In order to test the strength of adhesion of the eggs to the base of the container a plastic Pasteur pipette was used to create a jet of water fired at the eggs. All eggs stayed in place during this test, demonstrating the effectiveness of the adhesion. By chance the pond water contained a number of *Volvox* (a Chlorophyte alga). The rotating spheres of this species proved to be useful in the study of the adhesion properties of the egg's outer surface. Individual *Volvox* spheres that came into contact with an egg would immediately stop rotating and became adhered to it. They remained like this for the rest of the study period. It is also important to note that at this early stage each egg had its own very thin adhesion layer around the egg. A fine mounted needle was also used to test the adhesion by trying to move the eggs with its tip. Each egg tested was firmly adhered to the plastic.

Egg development and hatching

Egg development and hatching were as follows:

Day 1	eggs collected in clear plastic container containing pond water.
Days 2–6	a very noticeable yolk mass was visible taking up approx 60% of egg volume. During this time there was an increased build up of a gel-like substance around the eggs as the adhesive layer swelled. This formed a continuous mass engulfing the eggs (Plate 1) and trapped Volvox. There were no signs of any fungal growth around the eggs at any time.
Day 7	pigmented eyes and developing limbs and appendages were visible as distinct structures (Plate 2).
Day 8	some movement of developing embryos could be observed at intervals. The embryo appeared to rotate around the longitudinal axis of the egg.
Day 9	movements of the embryos were more frequent with legs and other structures clearly defined. The yolk mass had reduced significantly to less than 20%. Gentle probing of the gel mass around the eggs with a mounted needle showed it to have elastic like properties and no stickiness.
Days 11–13	Eggs started to hatch in the afternoon of day 11 with at least 50% hatched

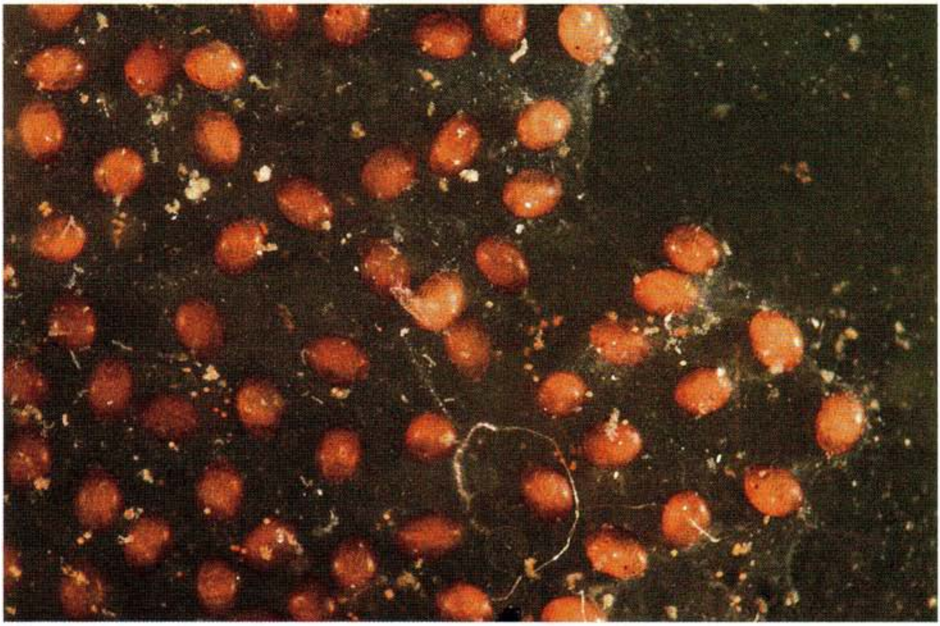

Plate 1. A mass of eggs of *Sympetrum striolatum* surrounded by a gel-like matrix. Note the margin of the gel.

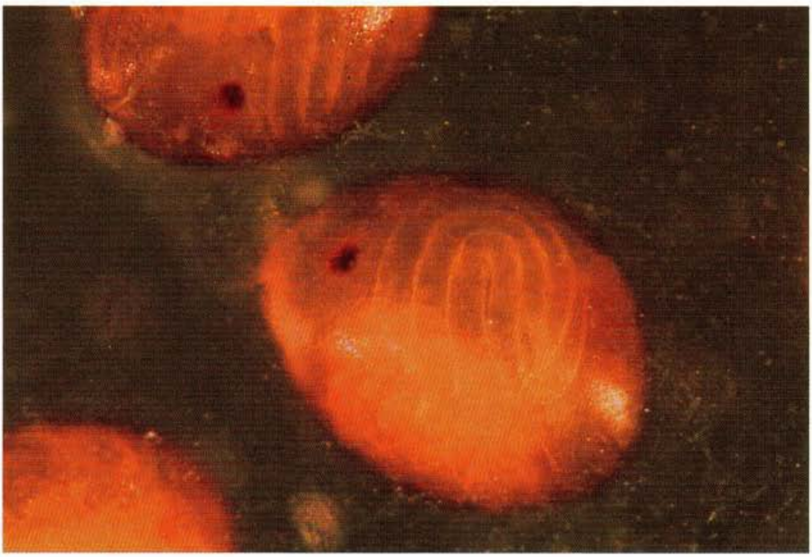

Plate 2. Eggs of *Sympetrum striolatum*. Note the heavily pigmented eye, the folded legs and the dense yolk mass.

by 17.30hrs. Hatching was preceded by internal movements at the head region followed by a sudden splitting down the longitudinal axis of the egg's upward facing surface. The top of the prolarval head was first to emerge followed by the upper part of the body in the prolarval sheath. From 345 eggs laid only three failed to develop and hatch. 65% of viable eggs hatched on day 11, 30% on day 12 and 5% on day 13.

Hatching and the prolarvae

Emergence of the prolarva from the egg occurred in two ways. Over 60% of prolarvae hatched from the egg and, whilst still partially attached to the egg, the 2nd instar larva emerged from the prolarval sheath. For purposes of clarity I shall refer to this as Type 1 hatching. In the remaining cases the prolarva broke clear of the eggshell and moved clear of the egg using wriggling movements (Type 2 hatching). Observations showed this to be a more drawn out emergence with the 2nd instar larva taking longer to appear. The mass of gel around the eggs may provide some resistance for the prolarvae to push against during this process. Prolarvae that moved clear of the gel mass had difficulties emerging, especially on days two and three of hatching. On these days mortality of prolarvae occurred, presumably as a result of what appeared to be fatigue. Over these two days 10% of hatching prolarvae died. The dead prolarvae became infected with fungal growth within hours.

The discarded eggshells had a dark brown coloration once the light coloured prolarvae had hatched. They were still firmly adhered to the base of the container and later attempts to dislodge them with water jets again proved difficult.

2nd Instar larvae

The 2nd instar larva emerges head first from the prolarval sheath. This was relatively quick in Type 1 hatchings compared to those of Type 2.

Two antennae appeared after the head was clear, followed by a distinctly bifid appendage that would later form the labium. The legs followed and the whole body pulled free of the prolarval sheath. The newly emerged larvae were highly transparent with a dense area of yolk still present in the mid gut area. They remained relatively motionless after emergence while muscular action of the abdomen starting rectal pumping. The cephalic heart could be seen at the head end and a rapid surge of gas was seen to fill the branchial network from the head end (Tillyard, 1917). Within seconds of this the larvae became active and started to move around. During this time the appendage that emerged with the head had curved around the front of the head to form the labium.

During the first day of 2nd instar larvae there was no aggression between individuals. It is presumed that nourishment was still supplied by the remaining yolk in the mid gut. Once this had depleted, larvae were observed attacking each other with their labia, presumably in search of nourishment. At this point, and as a result of some cannibalism, the study was terminated and the larvae were released back into the pond.

Discussion

Observation of developing eggs of *S. striolatum* has rarely been documented. During this short study the effectiveness of the egg's adhesive layer at attaching to the substrate was demonstrated. It provides an effective mechanism for securing the egg at the oviposition site. Eggs hatched 11–13 days after oviposition which compares with the 10–16 days recorded by Ottolenghi (1987) for eggs laid in September, 96% of which hatched in 10–12 days. Observations also suggest that the gel layer that spreads around the egg mass may play a role in protecting the eggs from predation and fungal growth and may also assist in the hatching process and the emergence of 2nd instar larvae from the prolarval sheath.

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Aspects of dragonfly flight digital still photography

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Summary

Photography of free flying dragonflies reveals aspects of their behaviour that are not possible under controlled conditions. By using modern digital still cameras, with high resolution and rapid autofocusing, new opportunities for flight photography can be realised in the field.

Introduction

Dragonflies exhibit amazing aerial abilities: "In their aerial agility and general mastery of flight, dragonflies, especially Anisoptera are without peers among other animals, except perhaps a few raptorial birds. On a scoring system that reflected versatility, dragonflies would almost certainly emerge as the best fliers this planet has produced" (Corbet, 1999). At least four distinct flight styles have been recognised (Rowe, 2004): counter-stroking (where fore- and hind-wings move up and down about 180 degrees out of phase), phased-stroking (where the hind-wings cycle about 90 degrees – a quarter cycle – before the fore-wings), synchronised-stroking (where fore- and hind-wings move in unison) and gliding. Many aspects of these flight styles are so rapid they go unnoticed by the unassisted human eye.

The study of flight behaviour has been limited by the ability of available imaging technology to record their flight movements. The studies of Rüppell (2002), using high speed filming techniques, have revealed many fascinating aspects of dragonfly flight behaviour. However, the cost of using such equipment is inhibitive for the casual user and therefore remains within the confines of academic study (Wakeling & Ellington, 1997a, b, c) and commercial film making. Recent scientific study of vortices and of shed vortices has revealed aspects of the physics of wing movement in dragonflies (Thomas *et al.*, 2004; Srygley, 2006). However, it is necessary to do this under controlled conditions whereby the effect of insect wing movement is filmed in special flight tunnels.

Still photography of insects in flight, including dragonflies, was pioneered by Dalton (1975, 1988, 1989). His technique involved using a specially modified camera shutter where the delay between shutter release and exposure was reduced to fractions of a second. To achieve these early still photographs a captive insect was directed down a flight tunnel to increase its probability of breaking a trigger beam which instantaneously fired the camera shutter. To freeze any movement high speed flash was essential. The flash duration needed to freeze an insect in flight has to be faster than 1/25,000 sec. This required the use of bulky, powerful units and subdued lighting conditions to reduce exposure of the film to ambient light. Such conditions were not conducive to natural behaviour. Brackenbury (1992) utilised similar techniques to photograph dragonflies and other insects in flight, summarising his reasons as follows: "The behaviour of insects is utterly unpredictable." "It is no use trying to photograph a flying insect with a hand-held camera. This is because the flight path of an insect is so unpredictable and the speed of human reactions so slow." Whilst these attempts at portraying dragonflies in flight are technically without equal in terms of depth of focus and sharpness they do *not* illustrate natural dragonfly flight behaviour. Controlled photographs are dated and should not be used to illustrate natural dragonfly flight behaviour. For example, the splayed leg positions of the dragonflies illustrated in photographs taken by such methods show unnatural behaviour as a result of the controlled conditions. In order to film or photograph truly natural behaviour one has to be prepared to reduce any disturbance to a minimum and do it in the field (Rüppel, 1989; May, 1991; see also Corbet, 1999).

Details of hovering flight were made by Norberg (1975) using a film speed of 80 frames s^{-1}. Rüppel (1989) photographed 20 species of odonate in flight on 16mm film and found that only 1–3% of about 12,000m of film were useful for the evaluation of flight. He used various techniques such as pinning down conspecifics and waving an insect net. More recently Rüppel & Hilfert have produced a number of high quality films of odonate flight, for example the flight of *Epiophlebia superstes*, using a high-speed camera at up to 500 frames s^{-1} (Rüppel & Hilfert, 1993). Wakeling *et al.* (1997a, b, c) filmed *Calopteryx splendens* and *Sympetrum sanguineum* on release from a box over a shallow pond in a greenhouse.

It is intended that this paper will demonstrate that, by using modern digital camera technology, it is now possible to photograph dragonflies in flight under natural conditions using a handheld digital camera.

Field craft

Flight photography of any wild animal presents a challenge. The success rate can be low, yet increases significantly if the photographer can predict where the action is most likely to take place. This requires a good understanding of the natural history of the target species. For bird photography the nest provides a predictable and well-utilised fixed point. Feeding, drinking or mating sites such as leks can also be productive in attracting the subject. Baiting can also make the outcome more predictable. However these options offer limited possibilities for dragonflies. It has been proposed that a tethered female dragonfly could serve as an attractant to males, but it is highly unlikely to give rise to natural behaviour and as such it should be discouraged.

Dragonflies spend a lot of time on the wing during favourable weather conditions. Males will fly to defend territory, search for mates and hunt for prey. The ability of the photographer to predict this type of behaviour will increase the chances of a successful flight photograph. One has to be able to predict where the males will patrol their territory. Will they hover in bays? Will they turn at the limits of their territory? Will they perch? Where are the females most likely to oviposit?

On the other hand females are much less predictable than males, although the chances of encountering them are increased significantly when they return to water to oviposit. Furthermore, a number of species, especially anisopterans, copulate briefly in flight at the breeding site and this presents an opportunity, yet considerable challenge, to photograph. With a good knowledge and an ability to predict odonate behaviour the possibilities for flight photography are greatly increased.

Results

The use of a Digital Single Lens Reflex (DSLR) camera (see appendix for specifications) has enabled a range of British species of Odonata to be photographed in flight (Table 1). The best results have been obtained when the flying subject can be isolated against a plain, uncluttered background. This enables the camera's autofocus to lock on to the difference in contrast and maintain focus throughout.

Dragonflies have been photographed successfully in free and hovering flight using a rapid burst of frames. Species that hover frequently will offer more opportunities than others. The frequent bouts of hovering exhibited by *Aeshna mixta* help to explain the preponderance of published photographs of this species in flight. For best results, as many frames as possible should be taken in each sequence (see caution below). This is especially important for capturing the moment at which a flying dragonfly turns and changes direction. On a number of occasions interesting behaviour has been missed or the sequence only captured after it had started.

Table 1. Species photographed in flight. Relative difficulty where ***** = very difficult.

Zygoptera		*Aeshna grandis*	****
Calopteryx virgo	****	*Anax imperator*	****
Calopteryx splendens	***	*Aeshna isosceles*	****
Coenagrion mercuriale	*****	*Cordulia aenea*	***
Coenagrion puella	****	*Somatochlora metallica*	****
Erythromma najas	***	*Orthetrum cancellatum*	***
Erythromma viridulum	***	*Orthetrum coerulescens*	****
Enallagma cyathigerum	**	*Libellula depressa*	****
Platycnemis pennipes	****	*Libellula fulva*	****
Anisoptera		*Libellula quadrimaculata*	*****
Aeshna mixta	*	*Sympetrum sanguineum*	**
Aeshna cyanea	**	*Sympetrum striolatum*	***

Observations on flight behaviour

Whilst studies have been made on dragonfly flight and the relative motions of the wings described, very little if any attention has been given to the use and positioning of the legs whilst flying. When in free or hovering flight odonates tuck the mid and hind pair of legs along the ventral surface of the thorax to present an optimal aerodynamic profile (Plates 1, 2). The front pair of legs is folded behind the eyes, although the arrangement is rather different in the two suborders. Thus, in the Anisoptera the front legs neatly fold vertically behind the large eyes (Plate 3) whereas in the Zygoptera they are folded upwards and slightly backwards (Plate 4). This is an aspect of flight that is not shown in flight photographs made under controlled conditions. Such photographs where all the pairs of legs are spread out indicate an individual that is likely to be showing signs of trauma and preparing to hold on to the first object it encounters.

Plate 1. Male Migrant Hawker, *Aeshna mixta*, in flight showing its aerodynamic profile. Note how the legs are folded under the thorax with the front pair folded behind the eyes.

There are occasions when the legs are used in flight. Some species of Anisoptera use their legs to clean the abdomen and the other legs whilst in flight (Cham, 2007). Flight photographs of dragonflies landing on a perch show the legs lowered just a split second before making contact. Sequences of photographs of libellulids landing show the hind pair of legs to be used first followed by the mid pair followed by the front pair. In *Libellula fulva* the front pair often remain folded behind the eyes during landing and while perched. Similarly, males when attempting to mate in flight also use the legs to take hold of the female. After take-off from a perch the legs are folded under the thorax within fractions of a seconds. In some species, such as *Platycnemis pennipes*, the legs are used to display to females and other males.

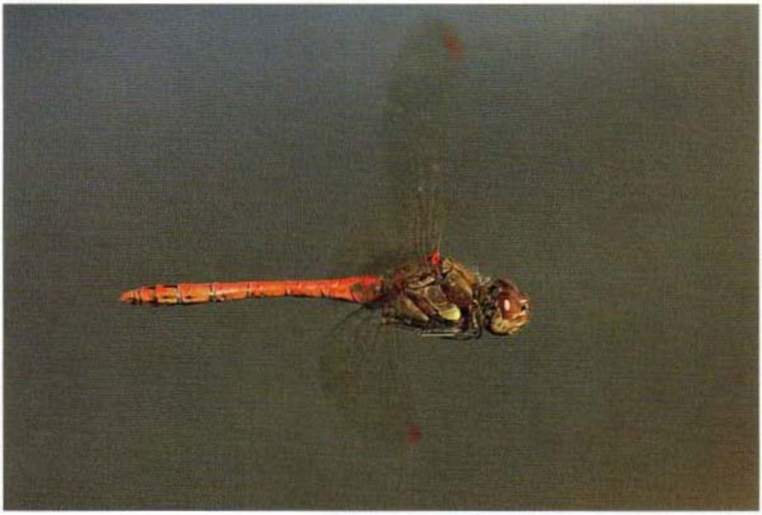

Plate 2. Male Common Darter, *Sympetrum striolatum*, in flight profile. Note how the legs are folded under the thorax with the front pair folded vertically behind the head.

Plate 3. Male Downy Emerald, *Cordulia aenea*, in hovering flight showing profile. Note how the legs are folded under the thorax with the front pair folded behind the eyes.

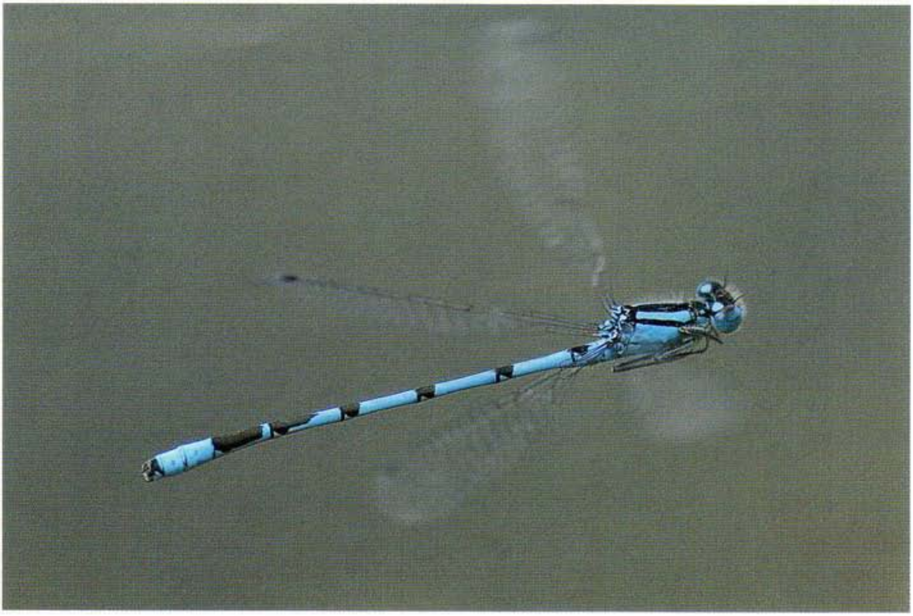

Plate 4. Male Common Blue Damselfly, *Enallagma cyathigerum*, in flight profile. Note how the legs are folded under the thorax with the front pair folded back at an angle.

Plate 5. Male Southern Hawker, *Aeshna cyanea*, turning. Note how the head is kept level whilst the rest of the body twists.

Plate 6. Male Migrant hawker, *Aeshna mixta*, exhibiting an extreme turn where the whole body is at 90 degrees to the head, which is maintained level to the horizon.

Plate 7. Head on view of the Downy Emerald, *Cordulia aenea*, in hovering flight showing the wings counterstroking. The front pair of legs is clearly visible folded behind the eyes.

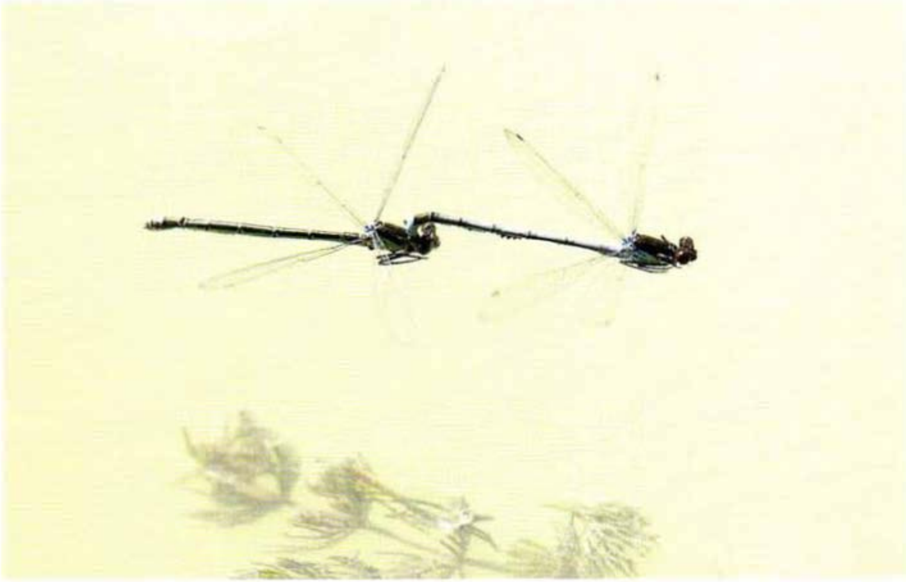

Plate 8. Tandem pair of the Red-eyed Damselfly, *Erythromma najas*, searching for an oviposition site. Note the synchrony of the wings suggesting a degree of co-operation.

Plate 9. Copulating pair of the Black-tailed Skimmer, *Orthetrum cancellatum*, in flight. Note how the front pair of legs in both sexes is folded behind the eyes.

Plate 10. Female Broad-bodied
abdomen. The yellow mass of eggs is visible at the tip of the abdomen.

Whether resting or in flight the head is maintained in an upright position by a dorsophotic response (Hisada *et al.*, 1965). Furthermore it is known that differences the position of the wings and body relative to the head are detected by a series of 'hairs' between the head and body (arrester system) acting as an inertial platform gravitational device (Mittelstaedt, 1950; Gorb, 1993). Flight photographs have elegantly shown how the head is maintained level when turning (Plate 5), even during extreme turns where the rest of the body is twisted through 90 degrees relative to the head (Plate 6). During hovering flight, wings beat by counter stroking whilst the head is maintained level (Plate 7). The abdomen is used as a rudder to increase stability and thus maintain the head in a level plane to best scan its surrounding environment.

Tandem pairs of Zygoptera are easier to photograph in
oviposition sites. Such photographs demonstrate a high degree of synchronised wing beats between the male and female (Plate 8).

Copulation and oviposition in flight can also be photographed. Tandem pairs of *O. cancellatum* have been photographed copulating in flight, revealing how the female uses its legs to cling to the male (Plate 9). Action photography of females ovipositing in flight can show eggs being released. This is useful for comparing species that oviposit exophytically by scattering their eggs. *Sympetrum striolatum* releases clusters of eggs by brushing them on the water surface whereas *S. sanguineum* releases single eggs by propelling them at plants growing in muddy areas. Females of *L. depressa* have been photographed with the egg mass clearly visible at the end of the abdomen at the point of release (Plate 10).

Capturing a rapid sequence of dragonflies, either in free or hovering flight, opens up the possibility of reconstructing the frames in a moving sequence on the computer. This can prove useful to study the relative movement of wings and body during flight. Such 'movies' can be prepared in Adobe Photoshop by preparing each photograph as a separate image layer. Building up layers in the sequence allows the images to be placed on a time line for playback as a movie using the Image Ready 'add-in' supplied with the software. By experimenting with the delay between images a pseudo slow motion movie can be developed to reveal the action. Whilst this is not a substitute for high speed motion filming it does reveal the relative movement of the dragonflies body that would not be apparent from a single photograph.

Conclusions

Digital still photography using a handheld camera *can* be used to photograph dragonflies in flight and opens up new possibilities to record and study aspects of flight behaviour. Modern digital SLR cameras currently have the fastest and most responsive autofocus systems available, enabling action behaviour too fast or unpredictable for manual or autofocus video cameras to capture. Still photography therefore provides a complementary method to high speed filming and video.

The limitations of current DSLR technology can be summarised as follows:

- the subject is sometimes difficult to isolate from the background leading to the autofocus 'losing' the subject. This is often more difficult with damselflies due to their thin bodies presenting less to focus on;
- caution! The small image buffer on some cameras leads to 'lock out' during rapid sequences as it processes the images to memory;
- narrow depth of field (focus) due to use of high shutter speeds and wide lens apertures can result in part of the subject being out of focus;
- one needs to work in bright natural light to achieve high shutter speeds to freeze the action.

Despite this, the technology will continue to improve and, as more photographers take up the challenge of flight photography, so we will gain more knowledge of flight behaviour. There still remains much scope for further work and new challenges such as: how do odonates capture their prey in flight – with their legs or with their mandibles?

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Appendix – The advantages of DSLR

- Hi resolution compared to digital video.
- Freedom to move around and use handheld.
- Ability to react quickly to rapid action.
- Reduced shooting costs per frame compared to film.
- Modern autofocus faster than the human eye.
- Rapid action sequences are possible.
- The magnification factor inherent in some digital SLR bodies (1.3, 1.6 times the lens magnification) allows the photographer to keep a greater distance without affecting the subject's natural behaviour.
- One can review the photographs within seconds of taking them to ensure that all is well recorded. This is especially useful if travelling to remote locations or where it is not possible to make a return visit.
- The built in Histogram allows evaluation of exposure. This is especially useful when working in difficult or changing lighting conditions, thus ensuring the correct exposure while still working in the field. With the delay involved in developing film this was a serious impediment at times.
- The EXIF metadata that is embedded with a digital image records the date and time the photograph was taken with details of exposure, shutter speed, aperture, correction factors, etc. This is especially useful for later review of filed photographs and for determining the speed of flight sequences.

The following specifications outline the recommended requirements for a Digital SLR camera for flight photography of dragonflies:

- Fast shutter speeds (1/1000th to 1/8000th second) to freeze wing movement. Slower speeds can also be used to deliberately blur the action for creative aspects of photography.
- A fast motor drive (>8 frames per second) allows more of the action to be recorded. Slower motor drives can be used but will limit the number of frames recorded and available for further examination.
- High megapixels (>8 megapixels) for recording fine detail and permitting great enlargement.
- The latest fast autofocusing lenses will improve the chances of successful flight photography.
- High ISO (a measure of sensitivity similar to film speed) with low noise. Digital cameras use either CCD or CMOS sensors to capture the image digitally. The sensitivity of the sensor can be controlled by varying the ISO value. Making the ISO setting more sensitive increases the noise levels in the image (similar to graininess in film). Camera manufacturers have different methods to reduce this during image processing and some are better than others.
- Quick start up time from off ensures that the camera is ready for action.

- Large image buffer. Caution! This is an often overlooked specification on DSLRs. The internal computer has to process the images and record them on the memory card. Cameras vary significantly in the speed at which they do this and they will lock out the user from taking more images until buffer is freed up. This can be a very frustrating experience for the flight photographer. The more expensive professional-DSLRs tend to have larger buffers.
- Digital flash memory cards store the images captured by the camera. In combination with the camera's processing power they play a significant role in the rate at which images are recorded. It is desirable to select cards with the fastest possible write speed. At the time of writing Compact Flash cards from several manufacturers are capable of write/read speeds of $40MBsec^{-1}$.
- Minimal delay between release and shutter firing. This is not a big issue on modern DSLR cameras but can be a problem with compact designs.
- Good range of close focusing (<1.5m) interchangeable lenses will enable frame-filling shots of the subject.
- Image stabilisation built into lens or camera can be helpful in some situations by reducing user induced camera shake.
- RAW image capture – the digital negative format that allows many possibilities for processing the final image. Images captured as jpeg in the camera limit possibilities later.
- In addition to the camera, a fast computer with image editing software will be necessary to process the images. Adobe Photoshop CS2 is the recommended option but other packages will suffice. The computer ideally should have plenty of hard disk space to run the program and store large images. Two hard drives, with one to serve as a scratch disk, can speed up the performance of memory hungry imaging programs such as Photoshop. Plenty of RAM is required. In general the RAM should be 3–4 times the size of the image (e.g. a 30MB image requires 120MB RAM). At the time of writing I use 2GB RAM. The demands on computers are likely to become greater as camera technology continues to improve.

The photographs used in this study were taken with a Canon EOS1D Mk2 fitted with either a Canon 180mm Macro or a Canon 300mm telephoto lens. It is highly probable that digital still photography technology will continue to improve even by the time this paper appears in print. It is recommended that the latest literature on digital photography be consulted.

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Mites on Odonates: Some early accounts and records (to 1950) from Britain

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Summary

Parasitic larval mites are found on the wings and bodies of odonates and exploit their hosts for food and dispersal. This has been known for over 250 years although early records show that the true relationship was misunderstood. Dragonfly and damselfly hosts are recorded from early records.

Introduction

Four years ago in *Dragonfly News* under Members' letters there was a piece headed 'Mites!' with the caption, "So the dragonflies have parasites to worry about, too … Does anyone recognise this problem or have further information?" (Tucker, 2002). Tucker included a photograph of a Red-eyed Damselfly (*Erythromma najas*), found on the Grand Military Canal at West Hythe in Kent, which had the ventral side of the abdomen completely covered with mites. Apparently in this area no other odonate species carried them. Tucker added, "I know nothing about this parasite – or where I might find reference to it."

Odonates have formed associations with several groups of invertebrates, in particular parasitic protozoans (gregarines) and mites, the latter being arachnids rather than insects. Much work has now been done on mites and the larval stages are known to be common external parasites of both anisopterans and zygopterans. The life cycle of these freshwater mites consists of egg, larva, nymph and adult, with resting stages after the larval and nymphal stages. The nymphs and adults are free-living freshwater predators. The larval mites have an initial phoretic stage on larval dragonflies or damselflies prior to their transfer onto adult odonates as the latter emerge from their larval skin. They then become parasitic, exploiting their hosts for both food and dispersal. The parasitic larval mite inserts its mouthparts into the cuticle of the adult odonate, forming a feeding tube or stylostome in the tissues of the host, and feeds on the haemolymph. Damage to the insect cuticle and the internal tissues takes place. During the feeding process the larval mites become engorged, swell to three or four times their pre-feeding size and then detach from the host to continue their life cycle in freshwater. The cues for detachment are unknown. Prevalence and intensity of infestation appears to depend on a variety of factors, including the age of the host, the time of year and the habitat; loads appear to "vary between years, populations and individuals within a population" (Corbett, 1999).

Records

The standard work on British freshwater mites is a Ray Society Monograph published in three volumes in the nineteen twenties (Soar & Williamson, 1925–1929). In it these authors list *Libellula*, *Agrion*, *Lestes*, *Calopteryx*, *Aeshna* and *Anax* as odonate hosts for mites adding, "we have also taken them [mites] on *Sympetrum meridionale*" (Soar and Williamson, **1**: 24).

Early authors believed the six-legged larval mite to be an insect until it was shown that the larva was a stage in the life cycle which gave rise to an eight legged nymph and adult characteristic of the arachnids. De Geer's work published in the eighteenth century consisted of seven volumes and marked a major advance in our knowledge of insects and included a volume on the main arachnid groups (De Geer, 1778). He may have been the first, or at least one of the first, to describe and illustrate the presence of a mite on a dragonfly (De Geer, 1778). He illustrated a mite from the thorax of an odonate with the name of *Acarus libellulae*. The four drawings showed the ventral side of an odonate with "nine little red spots" which were the mites, an enlarged larva, "round with short feet", obviously an engorged specimen, and a swimming stage with six fully extended legs.

Robert McLachlan (1837–1904), a Londoner, was an outstanding nineteenth century English entomologist who worked on the Neuroptera (which then included dragonflies and damselflies) and the Trichoptera (caddis flies). He was described as a 'zealous collector' and many of his specimens are held at the Natural History Museum in London and elsewhere in Britain. As a result of inherited wealth he was able to spend his entire life devoted to natural history and travel. McLachlan became a Fellow of the Royal Society in 1877 and was also a Fellow of the Linnean Society, editor and later proprietor of the Entomologists monthly magazine and President of the Entomological Society. In 1884 McLachlan published an important annotated list of British Odonates. In this, writing about *S. meridionale* he said, "Its liability to have the well known red *Acari* attached to the wings (sometimes in enormous numbers) is so marked as to be almost a specific character of the insect itself, few specimens being entirely free from them."

The authors of two early twentieth century books on dragonflies published in England (Lucas, 1900; Tillyard, 1917) also refer to mites being found on the surface of dragonflies.

William John Lucas had already published books on British butterflies and British Hawk Moths when in 1900 his book on British Dragonflies appeared. Surprisingly perhaps to today's naturalists, he refers to the fact that dragonflies "have been neglected" as a group and to the "paucity of field-workers" (Lucas, 1900). This is a beautifully illustrated work with coloured plates and figures, covering the life cycle and systematics of the genera and species found in this country. It also deals with such topics as habits, migration, distribution and breeding and there is a section on the Victorian passion, "preparing for the cabinet". There are several brief references to mites including the genus *Sympetrum* being attacked by mites. Lucas adds that, "A similar parasite has been noticed by the author on the thorax of *Pyrrhosoma nymphula* [Large Red Damselfly] and on that of *Ischnura elegans* [Blue-tailed Damselfly]."

Robert John Tillyard (1881–1937), also known as Robin, was born in Norfolk, studied mathematics at Cambridge and, following emigration to Australia, took up a school teaching post in mathematics at Sydney Grammar School, followed by zoological research at the university of Sydney. He also worked in New Zealand. Tillyard was an eminent zoologist and entomologist who became a Fellow of the Royal Society of London, specializing in the Neuroptera (see above) and in fossil insects. His book on the Biology of Dragonflies was published in 1917 and his work on British Liassic dragonflies was published by the British Museum (Natural History) in 1925. Until the time of his book on dragonflies, more than 90% of the papers written on the group were of a systematic nature and his book broke new ground in dealing with, amongst other topics, the internal anatomy, phylogenetics and physiology of dragonflies.

Tillyard's references to mites unfortunately relied heavily on earlier work, including the brothers Campion which was wrong in several aspects. Tillyard claimed that the mites are "false parasites", do not harm their hosts and that the mites place eggs or viviparous young in various positions on the body of the odonate. F. W. & H. Campion (1909) had published their work several years earlier. They believed at first that mites reach the body of the dragonfly by climbing up its legs, placed doubt on the fact that *Arrenurus* is the mite genus involved and questioned the true parasitic relationship of mites with dragonflies. However, in a footnote they correct one error made earlier in their work when referring to discussions one of them had with Dr F. Ris, who had observed mites passing from the larval skin on to the imago while emergence had been taking place. They list six species from their own collections which were infected with mites – Red-eyed Damselfly (*Erythromma najas*), Large Red Damselfly (*Pyrrhosoma nymphula*), Blue-tailed Damselfly (*Ischnura elegans*), Variable Damselfly (*Coenagrion pulchellum*), Azure Damselfly (*Coenagrion puella*) and Common Blue Damselfly (*Enallagma cyathigerum*).

It was not until Killington & Bathe (1946, 1947a, b) published their papers that reliable information was available about mites on odonates and their work was the first real scientific study of this subject in Britain. These authors stated that the association was a parasitic one, confirmed the view that the mites moved from the larval skin to the adult insect at eclosion, identified some of the larval mites involved and described their own breeding experiments. Work on the life cycle, including the development times for the various life cycle stages of the mites, was included. Killington & Bathe (1947a) also produced a tabulated list of hosts and parasites recorded in Britain – six species of host from England (Devon and Dorset, the areas where they worked) and Scotland (Sutherland, based on the records of a German worker) and four species of *Arrenurus* mite. The hosts were *Pyrrhosoma nymphula*, *Palaeobasis tenella* (*Ceriagrion tenellum*), *Coenagrion puella, Ischnura elegans, Ischnura pumilio and Enallagma cyathigerum.* Killington & Bathe also record "casual guests" on odonates, including the larva of a land mite, *Leptus sp.* (Killington & Bathe, 1946) and another type of freshwater mite, *Limnochares aquaticus*, which is normally found on pond skaters. In this case, the host records for *L. aquaticus* were recorded as *Palaeobasis tenella, Enallagma cyathigerum* and *Pyrrhosoma nymphula* (Killington & Bathe, 1947b).

Although this paper is concerned with information upto 1950, it should be noted that a recent review (Davids, 1997) lists as many as twenty-two odonate species from northwest Europe acting as hosts for water mites. The known relationships between the species of odonate and the larval mite species are tabulated. The most useful up to date source of reference and review of the literature on this subject can be found in Corbet (1999).

More information about the relationships between the two groups will increase if workers on dragonflies and damselflies can record instances of mites being found on odonate species. The author is willing to assist if contacted (pabrab@leeds.ac.uk) and would be interested in records and/or specimens to examine from home or abroad.

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Diel activity patterns in the adult Banded Demoiselle, *Calopteryx splendens* (Harris), and the effect of weather variables

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Summary

Diel activity patterns of the territorial zygopteran *Calopteryx splendens* (Harris) were studied in a well-established breeding population on the River Wharfe in northeast England. The effect of weather on the activity of the species was investigated. A bimodal activity curve was observed in both males and females, albeit rather more pronounced in the males. Male activity was largely influenced by reproductive behaviour, more specifically territory selection and defence, with short feeding flights within the immediate vicinity of the perch. Conversely, the activity patterns of the females incorporated more defined periods of foraging activity, quite distinct from periods of reproductive activity. The activity of the species significantly increased with increase in ambient air temperature and solar energy, whereas a significant negative relationship was found between the number of *C. splendens* in flight and increase in cloud cover, rainfall and wind speed. The observed activity patterns are discussed with reference to maximum profitability of specific activities, the physical condition of an individual and the recorded weather variables. There are implications for the long-term reproductive success of individuals where weather conditions suppress activity.

Introduction

The periods of activity in the relatively short lifetime of an adult odonate are fundamental in shaping the dynamics of the population. Essentially, feeding and successful reproduction (which includes activities such as territorial behaviour, courtship, mating and oviposition) are the driving forces behind, and the main constituents of, odonate activity (May, 1984). Indeed, many adult odonates concentrate their activity within the vicinity of localised breeding sites. However, different odonate species exhibit some variation in diel activity patterns, in some cases at least probably as a result of interspecific competition (May, 1979), prey availability and weather conditions (e.g. Mayhew, 1998). The last of these is often the most influential factor in controlling insect activity and several studies describe the detrimental effect of rainfall on insect survival (e.g. Weisser *et al.*, 1997). Wind and low light intensity often prevent insects from flying

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(Lutz & Pittmann, 1970; Weisser *et al.*, 1997), thus interrupting foraging and reproductive activity. Parr (1973) recorded the activity of the zygopteran *Ischnura elegans* and found that winds of 20 knots, continuous rain and a daytime temperature of less than 14°C inhibit flight, especially in combination. Flight is completely suppressed only by very strong winds, heavy and continuous rain or temperatures well below 14°C. However, *Enallagma cyathigerum* is capable of continued activity under conditions of fairly heavy rainfall (L. Ward, pers. obs.). In contrast, in *Pyrrhosoma nymphula* absence of sunlight inhibits flight (Mill & Bennett, pers. obs.). Positive relationships are generally found between insect activity and intensity of solar radiation (Lutz & Pittmann, 1970; May, 1979; Corbet, 1999) and increased air temperature (Casula & Nichols, 2003), although very high temperatures can reduce activity. Thus Weinheber (1993, cited in Corbet, 1999) reported considerable flight impairment, resulting in weight loss and increased predation, in a population of *Calopteryx haemorrhoidalis* on a stream in a hot, arid region of southern France.

The aims of this study are to describe the diel activity patterns of a well established, breeding population of *C. splendens* in northeast England and to investigate the relationship between actual numbers of *C. splendens* available for capture on each sampling occasion and various weather variables.

Materials and Methods

Between 24 June and 21 July 2000 a 1.5km stretch of bank of the River Wharfe at Newton Kyme, West Yorkshire, England (53°54'5"N, 1°16'57"W; British National Grid Reference SE245455) was surveyed for adult *C. splendens* between 0900 and 1600 (GMT). Insects were caught with a net and uniquely marked with a number on the left forewing using a fine indelible pen. Males were marked with even numbers, and females with odd to facilitate separation of male and female data for subsequent analysis. All animals were released as near as possible to their point of capture. The times of initial capture and recapture of each individual, on each sampling occasion, were recorded to the nearest minute. Where possible, marked individuals were subsequently recorded with binoculars. Data were pooled for all days to obtain information on times of peak activity for each sex.

Weather data collection

Ambient air temperature (°C) was recorded using a hand held thermometer and cloud cover was estimated using the octal system (eighths). A note was made whether rainfall had occurred at any point during the day. Other meteorological data were supplied by the University of Leeds Farms Weather Station, which was situated approximately 4km from the field study site. These data were 12 hour daily average readings of wind speed ($m\ s^{-1}$), grass temperature (°C), ground surface temperature (°C), total solar energy (G KJ), relative humidity (percentage saturation) and maximum hourly temperature (°C).

Results

At any given time the majority of individuals recorded were males. However, there was no sex bias (χ^2 (with Yate's correction)= 0.49, d.f. = 1, P> 0.05).

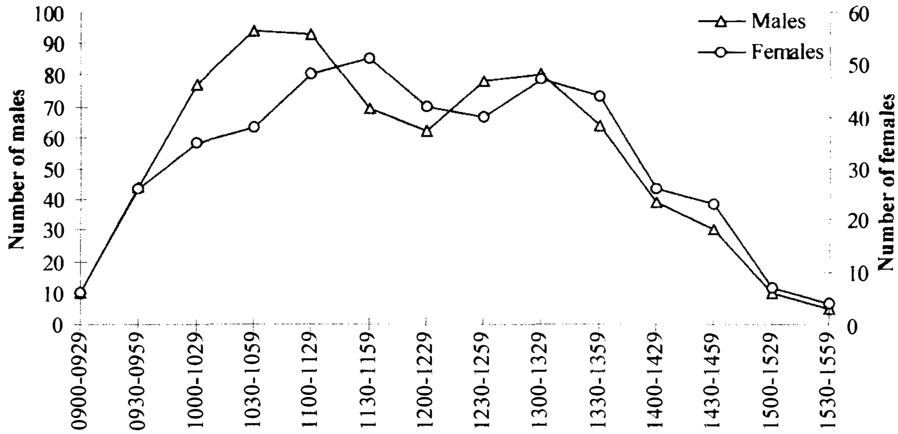

Figure 1. Activity patterns of adult *C. splendens* between the hours of 0900 and 1600 GMT (time is expressed as 24 hour clock), from 24 June to 21 July 2000.

Both sexes showed two main peaks in activity (Fig. 1). However, for the males the bimodal activity curve was rather more pronounced. A few males were already present at water when sampling commenced at 0900, but the number present rose rapidly between 0900 and 1100 (GMT). This coincided with their selection and occupation of territories (Ward, pers. obs.) and, by mid-morning, reproductive activity had commenced. Male activity was at its peak between 1030 and 1130, with a decline in numbers by approximately 30% between 1130 and 1200. Subsequently, a second peak in male activity was observed between 1300 and 1330.

The number of females captured increased more slowly, not peaking until 1130 to 1200, up to one hour later than the males. During early to mid morning many females were observed foraging in meadow away from water. A decrease in the number of females captured occurred between 1200 and 1300, with a subsequent resurgence in activity between 1230 and 1330. From 1330 onwards, the numbers of both sexes began to decline steadily and few animals were left in the study area by 1600.

Effect of weather on activity

The number of individuals captured per day was highly significantly correlated with all three measures of temperature (air, grass and ground) but particularly with air temperature (Table 1). A significant but lower positive correlation was also found between the number of individuals captured and both maximum temperature and total hourly solar energy. Significant negative correlations were found between the number of individuals captured and cloud cover, wind speed and relative humidity, with cloud cover having the greatest effect. In addition, a χ^2 test (with Yate's correction) revealed that, on days when rainfall had occurred (whether morning or afternoon), significantly fewer individuals were captured than on days when no rainfall had occurred ($\chi^2 = 486.31$, d.f. = 1, $P < 0.001$).

Table 1. Spearman's Rank correlation coefficients (2-tailed) of the number of adult *C. splendens* captured in relation to various weather variables. The ranges of each measured weather variable are given, the degree of correlation between the number captured and the weather variable (r_s), where 1.0 or −1.0 indicates a perfect correlation, and the probability (P) that each variable is significant (the lower the value the greater the probability of significance).

Weather variable	*Range*	r_s	*P*
Ambient air temperature (°C)	14–23	0.767	<0.001
Grass temperature (°C)	15–23	0.697	0.001
Ground surface temperature (°C)	18–32	0.668	0.002
Maximum temperature (°C)	15–23	0.587	0.010
Solar energy (G KJ)	432–1747	0.521	0.027
Cloud cover (eighths)	1–8	−0.784	<0.001
Wind speed (m s^{-1})	3–13.5	−0.593	0.009
Relative humidity (%age saturation)	62–86	−0.552	0.018

Discussion

The decline in the number of males captured just prior to midday may possibly have been because all available territories had been occupied by this time and those males without a territory left to find a territory elsewhere or became engaged in foraging. It is likely that many females remained foraging during early to mid morning either to avoid antagonistic males or to build up their food reserves to aid egg maturation.

The decline in activity in both sexes around midday, with a subsequent resurgence between 1300 and 1330, was probably due to individuals basking before commencing reproductive activity in the early afternoon. Corbet (1999) noted that male *Aeshna subarctica* showed basking maxima just before and just after the period of flight activity at water. From 1330 tandem pairs of *C. splendens* were observed at water and amongst the bankside vegetation, while many unattached males were involved in territorial activity at water. As may be expected in poikilotherms, reproductive activity commonly peaks at around midday or early afternoon (May, 1979; Mayhew, 1998). Higashi (1973) found that reproductive behaviour in *C. cornelia* was most frequent between 1100 and 1400. In the current study, activity had decreased considerably by late afternoon (1530 to 1600). Indeed, observations were generally reduced to small groups of males displaying at water and the occasional female foraging amongst the bankside vegetation. Higashi (1973) observed feeding flights in *C. cornelia* most often between 1600 and 1800.

The daily activity patterns of a species are often discussed in terms of the relative costs and benefits of particular activities (May, 1979; Casula & Nichols, 2003). Mayhew (1998) proposed a model for odonates with the assumption that individuals have the choice of either engaging in reproductive activity or foraging during fine weather, whilst remaining immobile between active days. Essentially, the decision to mate or forage is dependent on current energy reserves, although variability in activity patterns can occur depending on time of day. Additional constraints are imposed on individuals whose behaviour dictates the timing of certain activities, for example where the pressure to defend a territory is a concern. Mating and feeding behaviours are implicated through their depletory effects on energy reserves. Thus, the frequencies of each are mutually influential. In territorial species, such as *C. splendens*, reproductive activity is costly in terms of energy use, particularly for the males, thus frequent feeding bouts are necessary. The current study found that females spent time actively foraging before and after reproductive activity, thus allocating defined periods for the sole purpose of foraging. Conversely, the males tended to invest more time in territorial activity. Once a perch had been obtained, very short feeding flights within the vicinity of the perch were observed, but rarely foraging away from water.

Effect of weather

All temperate odonates must use behavioural strategies to maintain a body temperature within the range conducive to activities such as feeding and reproduction. During the hottest part of the day, *C. splendens* could be seen perching on vegetation. Reduced activity during periods of cool weather is a direct result of the odonates inability to become active below a certain body temperature. In a study of the Sardinian chalk hill blue butterfly, Casula & Nichols (2003) suggested that apparent temporary emigration could result from low temperatures causing inactivity of animals.

Sustained wind can serve to lower the ambient air temperature, in addition to disturbing the flight path of an insect on the wing. Search flights of the eulophid wasp *Sympiesis sericeicornis* were stopped when wind speeds exceeded 2m s^{-1} (Casas, 1989). In situations where relative humidity is high, such as during rain showers, or prior to storms, a decrease in air temperature and light intensity are often experienced. This, in conjunction with the potentially damaging effects of rainfall, serves to reduce activity in *C. splendens*. Weisser *et al.* (1997) found that during rain the aphid parasitoid *Aphidus rosae* stopped all foraging activities, whilst during periods of increased wind speed it foraged at a reduced rate, with a concurrent increase in the rate of parasitism in encountered aphid colonies. Juillet (1964) found that parasitic ichneumonids and braconids were most active when the wind velocity was low. However, the ichneumonids were most active in cool, humid conditions whilst the braconids preferred warm, dry conditions. The observed difference in behaviour between the two families coincides with the fact that ichneumonids predominantly parasitise forest insects and braconids predominate on agricultural insects.

Thus an individual may choose its activity based on maximum profitability, and important factors are its physical condition and environmental conditions. The detrimental effects of adverse weather conditions have implications for the population dynamics of species by potentially affecting the lifetime reproductive success of individuals.

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Vagrant Emperor *Anax (Hemianax) ephippiger* (Burmeister, 1839) – a new breeding species for Bulgaria

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Summary

In July 2004 the first British Dragonfly Society trip to Bulgaria took place, led by Dave Smallshire. The trip was hosted by Bulgarian dragonfly expert Milen Marinov and Stoyan Beshkov. On the last day, at the last site visited (a complex of river, streams and ponds near Novo Konomladi in the south-west of the country) I collected several exuviae, one of which was later identified as *Anax (Hemianax) ephippiger*. This represents the first proof of breeding for this species in Bulgaria. The history of *A. ephippiger*, with particular reference to Bulgaria, is discussed.

Introduction

The Vagrant Emperor *Anax (Hemianax) ephippiger* is a species that occurs mainly in strongly seasonal parts of Africa, the Middle East and south-west Asia (Askew, 1988). It wanders to and fro to breed after the rains and in some years migrations span across Europe (Dijkstra, 2006), mostly in the Mediterranean region but it occasionally reaches England and sometimes as far north as Iceland (Norling, 1967; Mikkola, 1968; Tuxen, 1976). It has been known to breed occasionally in southern Europe (Askew, 1988) with records of teneral adults from the Camargue (Jurzitza, 1964) and from Huelva, Spain (Belle, 1984).

The history of *Anax (Hemianax) ephippiger* in Bulgaria

The possibility of *A. ephippiger* breeding in Bulgaria was suggested by Milen Marinov (Marinov, 2001). His review of known *A. ephippiger* records to that time shows the first record for the species to have been from near Bourgas on the Black Sea coast prior to 1923. There is then a long gap until the next known records in 1970/1971. A smaller time gap occurs until a male was recorded in August 1982 from Kranevo, then during five days in August 1983 several individuals, including one female, were noted from Dourankoulak. From this date, records occur more frequently and often include more than one individual.

In 1989 four adult specimens, three male and one female, were noted from Srebarna. This record is of particular interest because one of the males was described as "not fully mature". The possibility of *A. ephippiger* breeding within Bulgaria was also suggested by the presence of a mated pair at Stamopoulo in April 1991 and by another pair at Atanasovsko Lake in May 1995 (Marinov, 2001). This latter location, a large lake on the east coast of Bulgaria near Bourgas, was also the general location where two males and one female were noted separately between 16 September and 1 October 1990.

As indicated above, most of the records of *A. ephippiger* from Bulgaria before 2000 refer either to single individuals or to small groups. Most records are from the Black Sea coast or from the Struma river valley in south-west Bulgaria. Records in 2000 and since have show a little more scatter (Marinov, pers. com.) but still include sites on the Black Sea coast. This increase in the number of records in recent years may be a genuine reflection of events or could be due to a greater awareness of the species amongst recorders. However, it seems likely that Bulgaria lies on one of the eastern Mediterranean migration routes for a number of large dragonfly species, including *A. ephippiger*, and that movement of these species within this part of Europe is increasing.

Marinov witnessed a mass migration of dragonflies along the Black Sea coast that lasted for two days in 1990 (Marinov, pers. com.). More recently, at the end of August and beginning of September 2004, he noted large numbers of dragonflies on the northern Black Sea coast, including at least one male specimen of *A. ephippiger*. At about the same time, but on the other side of the Black Sea, two of his colleagues reported seeing huge swarms of large dragonflies, perhaps numbering thousands of individuals. These colleagues collected various specimens from near the town of Tuapse on the coast of Russia; specimens that included two male and one female *A. ephippiger* collected on 2 and 3 September 2004.

It is possible that the Bulgarian records of *A. ephippiger* that appear almost annually between 1990 and 2004 stem from similar mass migrations and that several opportunities for the species to breed within the country have occurred. One record of interest here is a male specimen found on 22 August 2002 at 1800 metres above sea level on the Pirin mountain. This mountain lies to the north west of Novo Konomladi where the *A. ephippiger* exuvia was found two years later (see below). The altitude of the 2002 record shows that mountains such as this need not act as a barrier to this species.

Completing the picture, Bulgaria is known to contain a number of wetlands suitable for the temporary breeding of *A. ephippiger*. Many of these wetlands are already home to Lesser Emperor *Anax parthenope*, a species that has itself expanded in range since the 1990s (Dijkstra, 2006) and is already common along the eastern coast of Bulgaria. The two species are known to occur together in nearby Greece (Holusa, 1998), so it would appear that by 2004 a number of conditions were right for *A. ephippiger* to breed in Bulgaria.

The site near Novo Konomladi

The 2004 British Dragonfly Society trip to Bulgaria visited four main areas in the south-west of the country, the last area being centred on the town of Melnik. The site to the west of Novo Konomladi was visited on the afternoon of 9 July 2004. The wetland area here consisted of ponds, wet hollows and streams adjacent to a small river, the River Melnishka. There was evidence at the site that the area had been used for gravel extraction in the past. The main pond, bordered by the track on one side, was embanked on the other three sides so that its surface was above that of the nearby river. It is approximately 100 metres above sea level. Weather at the time was hot, dry and still.

The whole area was thoroughly searched for dragonflies and exuviae. Species present and on the wing included Scarlet Darter *Crocothemis erythraea*, White-tailed Skimmer *Orthetrum albistylum*, Emperor Dragonfly *Anax imperator*, Norfolk Hawker *Aeshna isosceles*, Marshland Darter *Sympetrum depressiusculum*, Banded Darter *S. pedemontanum* and Green-eyed Hook-tail *Onychogomphus forcipatus*. The river held a strong population of Banded Demoiselle *Calopteryx splendens*. The total number of species that have been found in the region of Novo Konomladi is 34, twenty of which were seen on this trip (Table 1).

Table 1. Check-list of the 34 Odonata species found near Novo Konomladi. * indicates species seen in this region in July 2004

Zygoptera	_Enallagma cyathigerum_	*_Orthetrum cancellatum_
*_Calopteryx splendens_	_Ischnura pumilio_	*_Orthetrum albistylum_
Lestes parvidens	*_Ischnura elegans_	*_Orthetrum brunneum_
Lestes barbarus	**Anisoptera**	*_Orthetrum coerulescens_
Lestes virens	_Aeshna mixta_	*_Crocothemis erythraea_
Sympecma fusca	_Aeshna affinis_	*_Sympetrum striolatum_
*_Platycnemis pennipes_	*_Aeshna isosceles_	_Sympetrum meridionale_
*_Erythromma viridulum_	*_Anax imperator_	*_Sympetrum fonscolombii_
*_Erythromma lindeni_	_Anax parthenope_	*_Sympetrum sanguineum_
Coenagrion scitulum	*_Onychogomphus forcipatus_	*_Sympetrum depressiusculum_
Coenagrion ornatum	_Cordulia aenea_	*_Sympetrum pedemontanum_
*_Coenagrion puella_	*_Libellula depressa_	_Selysiothemis nigra_

On the edge of the main pond I stopped to observe a male specimen of Small Red-eyed Damselfly *Erythromma viridulum*. Next to it, approximately 40cm above the water surface in a small clump of rushes, I found an exuvia of what at first appeared to be an *Aeshna* species. I collected the exuvia and labelled the pot, but paid no further attention to it at the time.

Examination and identification of the exuvia

It was not until August 2004 that I examined all the exuviae I had collected in Bulgaria in any great detail. It was at this point that I realised the exuvia from Novo Konomladi was not of an *Aeshna* species as I had assumed, but of an *Anax* . However, at just 44mm it was too small for *Anax imperator* or *A. parthenope* and was of a species I had not encountered before. Careful examination of this exuvia and reference to Askew, 1988 led me to the conclusion that the exuvia belonged to a male *A. ephippiger*. I contacted Milen Marinov about my conclusion and he informed me that if my identification was verified, it would provide the first confirmed breeding record of *A. ephippiger* in Bulgaria.

I sent the exuvia to Graham Vick who kindly examined it for me and confirmed my identification. He informed me that this exuvia was identical to a specimen he possessed from Nigeria (Nigeria, Vom, 22 Oct 1960 reared, Robert Gambles determined) and also with the description of DeMarmels (1975) and the keys produced by Chelmick (1999). In particular, the size and head shape were obvious characters; also the spines on the abdomen, the shape of the labium and the structure of the cerci, paraprocts and epiproct.

Conclusions

Many dragonfly species are currently increasing their range across Europe. Vagrant Emperor *Anax (Hemianax) ephippiger* would appear to be one such species, although to a lesser extent than other species such as Emperor Dragonfly *Anax imperator* and Lesser Emperor *A. parthenope*. There has certainly been an increase in records of *A. ephippiger* from Bulgaria since 1990 and some indication of possible breeding in 1989, 1991 and 1995. The finding of an exuvia of *A. ephippiger* from a site near Novo Konomladi on 9 July 2004 provides the first proof of breeding of this species in Bulgaria.

Acknowledgements

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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 format either on disk or by e-mail.

Typewritten manuscripts should be produced using black ribbon, double-spaced, on one side of the page only and with margins at least 25mm at the left, top and bottom. Text pages should be numbered and footnotes avoided.

Words that are to appear in italics (e.g. names of genera and species, though not of families) should be underlined if an italic font is not available.

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 2004.

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 this form:

Hammond, C. O. 1985. *The dragonflies of Great Britain and Ireland.* 2nd edition (revised by R. Merritt). Harley Books, Colchester. 116 pp.

Longfield, C. 1949. The dragonflies of the London area. *The London Naturalist* **28**: 90–98.

Titles of journals should be written out in full.

Tables should be presented on separate, unnumbered pages.

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Figures should be prepared in black ink, and scaled to allow a reduction of 1.5 to 3 times.

The legend for each table and illustration should allow its contents to be understood fully without reference to the text. The approximate position of each table and figure should be indicated in the text.

SCIENTIFIC AND ENGLISH NAMES OF BRITISH ODONATA

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

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