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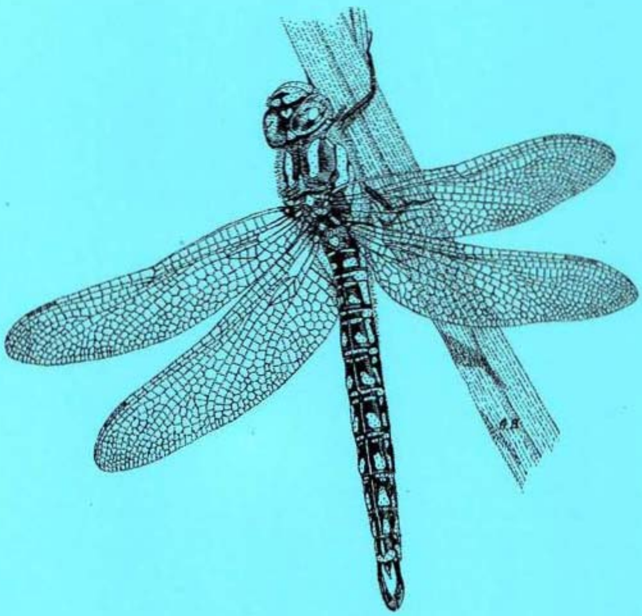

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Front cover illustration: Hairy Dragonfly *Brachytron pratense*, Holborough Marshes, K, 26 May 1997, by Gill Brook.

Use of the herbicide Glyphosate to control Common Reed (*Phragmites australis*) and its effects on dragonfly populations

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Introduction

The stage of a pond's development when it consists of open water fringed by aquatic plants is the best stage for most dragonfly species. In the course of normal seral development, ponds often get shaded out by too many aquatic plants and so begin to lose their dragonflies. Therefore, owners of ponds who want to give priority to dragonflies often need to control aquatic vegetation in, and sometimes around, their ponds. Physical removal of the vegetation can be very time-taking, and often involves much disturbance of the habitat; therefore chemical treatment can be preferable. There is little published work on the effects of using aquatic herbicides on dragonfly populations and therefore it seems worth recording my recent experience in controlling Common Reeds (*Phragmites australis*) on my pond in Cambridgeshire.

The problem

My pond was constructed in 1983. It is *c.* 38m long and 13m wide at its widest point. It has no inlet or outlet, and is well sheltered. Its aquatic flora consists of about a dozen species and *c.* 14 species of dragonflies breed in it in most years. Six further species have visited it, and one of these has bred in it. For a full description of the pond and its flora and fauna see Moore (2002, 2002a).

Common Reeds colonized the pond naturally in 1988, five years after its construction. They spread each year, notably in 1996 following a severe drought, when the water level of the pond was considerably lowered. By 2003, reeds covered most of the west end of the pond, and there was an indication that dragonflies were beginning to decline. Until then I had kept the reeds in check by cutting them by hand from the shore and from a boat. By 2003, it was clear that I could no longer do this effectively, so I decided to get rid of the reeds completely by spraying them with a herbicide.

The treatment

I sought advice from a specialist weed control service and was strongly advised to use Glyphosate to control the weeds on my pond. Glyphosate (glyphosate isopropyl ammonium), which is marketed under the name of Roundup®, is a broad spectrum, non-selective herbicide that leaves no residue. It is effective in killing all types of plants, including grasses, perennials and woody plants. It is absorbed by foliage and non woody stems and is systemic, i.e. it is translocated through the plant. It gives better control of weeds if it is applied at a later stage in the growing season (Worthing & Hance, 1991). Glyphosate has a low acute toxicity: the LD50 for the rat (*Rattus norvegicus*) is 5,600mg/kg of body weight and 950mg/kg for the mallard (*Anas platyrhynchos*). The LC50 for trout (*Salmo trutta*) is 86mg/l and more than 280mg/l for *Daphnia*. (The LD50 is the dose of a chemical that kills 50 per cent of a sample population. The LC50 is similar, but refers to a concentration rather than a dose.) Glyphosate has been used for about 30 years and has a good safety record. Glyphosate has very different effects on different plants. For example, the filamentous alga *Cladophora*, Canadian Waterweed (*Elodea canadensis*), Ivy-leaved Duckweed (*Lemna trisulca*) and the pondweeds *Potamogeton crispus* and *P. pectinatus* are resistant to it, whereas the water-lilies *Nuphar lutea* and *Nymphaea alba*, the Bulrush (*Typha latifolia*) and the Common Reed (*Phragmites australis*) are susceptible (Fryer and Makepeace, 1978).

The reeds on my pond were sprayed on 23 July 2003 using Roundup® Pro-Bioactive containing Glyphosate at 360g/l. It was applied at the concentration of 5 litres per hectare in 250 litres per hectare of water using an 04 flat fan nozzle. A repeat spraying was required on 6 September 2003. Roughly the western half of the pond was sprayed, with a few outliers of reeds in the eastern half; most of the eastern half was left unsprayed. Individual plants of Yellow Iris (*Iris pseudacorus*), Flowering-rush (*Butomus umbellatus*) and Branched Bur-reed (*Sparganium erectum*) were growing among the reeds; as far as possible spraying of these was avoided. Later the dead reeds were cut from the shore and from a boat, then removed from the pond in the period 10 January to 3 February 2004.

The effects of Glyphosate spraying on the aquatic flora of the pond

Observations were made on the aquatic flora of the pond in the summer of 2004 to determine:

1) the effectiveness of spraying the reeds;
2) what effects, if any, Glyphosate had on aquatic plants in the unsprayed area of the pond;
3) what effects Glyphosate had on aquatic plants growing among the reeds;
4) what species colonized the reed bed following the spraying.

The results of these observations are summarized in Table 1. The numbers of the ten species growing in the untreated part of the pond in 2004 after spraying were similar to those recorded in 2003 before spraying. In the sprayed area all the reeds were killed. However, individuals of six other species survived the spraying. Also, by the end of the summer of 2004 Common Duckweed (*Lemna minor*) had colonized the area previously covered by reeds, and had also appeared in parts of the unsprayed area. The flora in

Table 1. The effects of spraying Glyphosate on the aquatic flora of a Cambridgeshire pond. Data on abundance are presented before spraying in 2003 and after spraying in 2004. Numbers of mature plants are represented as '+' ≤ 10; 10< '++' <100; '+++' ≥ 100.

Species	East Part of Pond		West Part of Pond	
	Unsprayed		Unsprayed	Sprayed
	2003	2004	2003	2004
White Water-lily *Nymphaea alba*	+	+		
Greater Spearwort *Ranunculus lingua*	++	++		
New Zealand Pigmyweed *Crassula helmsii*	+++	+++		
Flowering-rush *Butomus umbellatus*	++	++	++	++
Water-plantain *Alisma plantago-aquatica*	+	+	+	+
Broad-leaved Pondweed *Potamogeton natans*	+	+		
Common Duckweed *Lemna minor*		++		+++
Sedges *Carex* spp.	++	++	+	+
Common Reed *Phragmites australis*			+++	
Branched Bur-reed *Sparganium erectum*	+++	+++	++	++
Bulrush *Typha latifolia*	+++	+++	++	++
Yellow Iris *Iris pseudacorus*	+++	+++	+	+

2005 was essentially the same as in 2004 except that there was much less Common Duckweed in the area which had been sprayed, and New Zealand Pigmy-weed (*Crassula helmsii*) had colonized some of its edges, and green algae were abundant.

The effects of Glyphosate spraying on the dragonfly populations of the pond.

In 2003 and 2004, I continued the routine observations on dragonflies that I have made on the pond since it was constructed in 1983. Whenever possible I recorded the number of mature male dragonflies at about solar midday on fine days. I also recorded the teneral dragonflies and exuviae that I observed when making the transects.

Table 2. Presence of teneral dragonflies and exuviae on Glyphosate sprayed and unsprayed areas of a Cambridgeshire pond in 2003 and 2004.

Species	East Part of Pond		West Part of Pond	
	Unsprayed		Unsprayed	Sprayed
	2003	2004	2003	2004
Large Red Damselfly *Pyrrhosoma nymphula*	+	+	+	+
Azure Damselfly *Coenagrion puella*	+	+	+	+
Common Blue Damselfly *Enallagma cyathigerum*	+	+	+	+
Blue-tailed Damselfly *Ischnura elegans*	+	+	+	+
Migrant Hawker *Aeshna mixta*				+
Four-spotted Chaser *Libellula quadrimaculata*		+	+	
Common Darter *Sympetrum striolatum*	+	+	+	+
Ruddy Darter *Sympetrum sanguineum*	+	+	+	+

Table 2 shows the species observed to emerge from unsprayed and sprayed areas of the pond in the two years. Spraying had no major effect on emergence. In Table 3, the maximum number of mature males of each species observed

2004 are compared. The values are related to the mean in the period between 1985 and 2002 (Moore, 2002, 2002a). In 2004 following spraying, the number of males was fewer than in 2003 before spraying in one species, the same in four species but more in ten species. The one species with fewer males in 2004 than in 2003 was the Large Red Damselfly *Pyrrhosoma nymphula* (Sulzer), of which many emerged, but which appeared to be killed off later by a long period of exceptionally bad weather that followed emergence. The values of 2003 and 2004 need to be related to previous years. In 2003, the number of males was below the mean in six species, equal to it in six and above it in three species. In 2004, the number of males was below the mean in one species, equal to the mean in three and above it in eleven species. The Black-tailed Skimmer *Orthetrum cancellatum* (L.), which had only been recorded in four previous years, was recorded at its highest level. The figures show that, in general, the populations of the male dragonflies at the pond following the destruction of the reed bed were higher than in 2003 and higher than the mean for the previous years.

Many Azure Damselflies *Coenagrion puella* (L.), which spend one year in the larval state, emerged from the sprayed area in 2004, as did many *P. nymphula* which had been sprayed during the second year of their larval state. The possibility remains that spraying

Table 3. Greatest number of male dragonflies observed on one transect of a Cambridgeshire pond before and after spraying with Glyphosate.

Odonata Species	Before spraying 1985–2002			Before spraying 2003	After spraying 2004
	Years	Range Observed	Mean		
Emerald Damselfly *Lestes sponsa*	18	2–14	7	1	14
Large Red Damselfly *Pyrrhosoma nymphula*	15	1–8	2	3	1
Azure Damselfly *Coenagrion puella*	18	6–113	45	51	51
Common Blue Damselfly *Enallagma cyathigerum*	18	1–30	10	23	28
Blue-tailed Damselfly *Ischnura elegans*	18	3–30	10	4	30
Migrant Hawker *Aeshna mixta*	18	1–4	2	2	4
Southern Hawker *Aeshna cyanea*	18	1–2	1	1	2
Brown Hawker *Aeshna grandis*	18	1–2	1	1	1
Emperor Dragonfly *Anax imperator*	15	1	1	1	1
Hairy Dragonfly *Brachytron pratense*	9	1–2	1	1	1
Four-spotted Chaser *Libellula quadrimaculata*	15	1–4	2	1	6
Broad-bodied Chaser *Libellula depressa*	10	1–2	1	1	2
Black-tailed Skimmer *Orthetrum cancellatum*	3	1	1	0	3
Common Darter *Sympetrum striolatum*	18	4–13	7	5	10
Ruddy Darter *Sympetrum sanguineum*	16	1–7	4	1	7

might have affected *P. nymphula* larvae which
therefore more exact observations of emerging *P. nymphula*, and of *C. puella* for comparison, were made in 2005. Of the 84 *C. puella* observed emerging in 2005, 46 were in the area that had been sprayed and 38 were in the area that had not been sprayed. By contrast, of the 18 *P. nymphula* observed emerging in 2005, only four were in the sprayed area and 14 were in the unsprayed area. The numbers observed were small, and the fewer records from the sprayed area can be explained by movements of *P. nymphula* larvae since spraying, but they may indicate that at least some of the *P. nymphula* that were in their first year of larval life when they were sprayed may have been affected by it.

In 2005, no *O. cancellatum* was observed. On 21 June 2005, a female White-legged Damselfly *Platycnemis pennipes* (Pallas) was seen near the edge of the pond where it had been sprayed. This insect was clearly a vagrant; it brings the total of dragonfly species observed on the pond since 1984 to 20.

The effect of Glyphosate spraying on the pond's vertebrate fauna.

A pair of Reed Warblers (*Acrocephalus scirpaceus*) had bred in the reeds during 2002 and 2003. In 2004 the male appeared in the spring and sang for a few days in bushes near the pond edge but then disappeared. Grass snakes (*Natrix natrix*) and Moorhens (*Gallinula chloropus*) were both seen on unsprayed and sprayed areas of the pond during 2004 and 2005. The moorhen nested among dead reed stems left round the island in 2004 and on the pond's edge in 2005. In both years a chick was reared.

Smooth Newts (*Triturus vulgaris*) were observed in unsprayed areas of the pond in 2004 and in unsprayed and sprayed areas in 2005. However on 21 July 2004 a dying Smooth Newt was seen floating on the surface of the pond in the area that had been sprayed in 2003. Its cause of death was not known, but as there are records of amphibians being affected by Glyphosate (Relyea, 2005) it is possible that this individual was a casualty of Glyphosate or of the surfactant with

Discussion

The results of this study were to be expected, but two points need discussion: First, how did the plants like Flowering-rush, Branched Bur-reed and Yellow Iris, which are susceptible to Glyphosate and were growing among the reeds survive being sprayed? My weed control specialist pointed out that since the reeds were taller than these plants, he was able to spray the reeds while largely avoiding the plants growing below them. Also, in some long rooted species, Glyphosate may not reach more than 1.2m down the root system, thus enabling plants to recover with what is left of the living root stock.

The second question is: What effect of spraying caused such a quick response by adult male dragonflies? Poisoning and removing the reeds reduced the shading of the water and hence increased its warmth; it made it much easier for dragonflies to fly over it and it increased visibility. Enough perching places (and emergence sites) remained. Probably all these factors worked together to improve the habitat for the dragonflies.

The reappearance of *O. cancellatum* after a long absence from the site was probably due to changes in the pond edge. For several years the pond edge, partly shaded by reeds, had not provided the basking places required by this species. Following the removal of the reeds, much of the shore was covered by compacted dead reeds, which were noticeably warmer than the live grass they replaced and probably provided the necessary basking places. The last time three *O. cancellatum* had been observed was in 1984, shortly after the pond was dug, when much of its edge was still bare soil. No basking places were provided in 2005 and no *O. cancellatum* was observed.

Conclusions

Spraying the encroaching reed bed on my pond in August 2003 succeeded in killing off all the reeds. One pair of Reed Warblers lost their habitat and disappeared. Otherwise there was no evidence of harm to Moorhens, Grass Snakes, Smooth Newts and dragonflies; on the contrary, the increase of suitable habitat allowed the populations of adult insects to increase. It is just possible that some Smooth Newts and some larvae of *Pyrrhosoma nymphula*, which were sprayed in the first year of their development, were adversely affected.

In the instance of my pond, spraying was clearly beneficial. To what extent is my experience generally applicable? The toxicity of a herbicide can be affected by concentration levels and formulations; the effects in the field can be affected by weather and the date of spraying. Nevertheless when the choice is between losing most if not all of the dragonflies and relatively small risks attendant on any herbicide application, the risk is obviously worth taking. The experience of others in similar circumstances would be valuable.

Acknowledgement

My thanks are due to Mr. Rod Thompson of Complete Weed Control, who not only cleared my pond of reeds most effectively, but also provided me with data about the herbicide and useful information about its effects.

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Observations on emergence and duration of adult life of the Hairy Dragonfly *Brachytron pratense* (Müller)

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Introduction

The Hairy Dragonfly *Brachytron pratense* (Müller) is the first large dragonfly to emerge in Northamptonshire, in common with most other counties where it breeds. Its range in the county has been expanding over the last eight years (Tyrrell & Brayshaw, 2004) and there are now several sites where the population size is sufficient to permit studies that will add to our knowledge of this important species. Perrin (1999) summarized the collective knowledge to date and stated that much more was to be learned about the behavioural characteristics of *B. pratense*.

Methods

During the 2005 flight season, regular visits were made to observe emergence behaviour at two breeding sites that support large numbers of *B. pratense*: Ditchford Lakes and Meadows Local Nature Reserve (British National Grid Reference SP 934682) and Wilson's Pits (SP 945683). Surveys were carried out at Ditchford on a daily basis for the first three weeks in May, and then every few days. Observations on emergence were made at weekends from about 0830h, and collection of exuviae predominantly between 1230h and 1315h on weekdays. A transect walk was made along the same stretch of the main pit at Ditchford, covering the southern and eastern margins. The northern and western margins are tree lined with no emergent vegetation and do not provide much suitable habitat for emergence.

Exuviae were collected, measured and the sex was determined. The emergence patterns for both sexes are presented both as a bar chart and as a cumulative percentage of the total emergence in Figure 1.

Field observations

The favoured emergence supports were predominantly sedges (*Carex* spp.), although bur-reeds (*Sparganium* spp.), horsetails (*Equisetum* spp.) and Yellow Iris (*Iris pseudacorus*) were occasionally used. In areas where there was a choice of emergence support, sedges were favoured. No exuviae were recovered from bulrushes (*Typha* spp.) or Common Club-rush (*Schoenoplectus lacustris*), despite their importance to this species for oviposting and larval habitat (Tyrrell & Brayshaw, 2004). Early in the season, emergence tended to

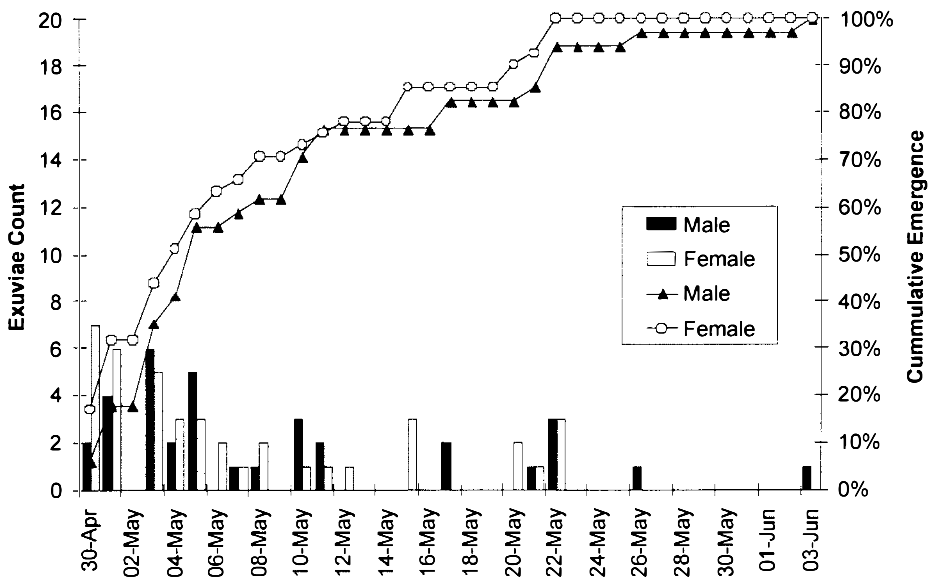

Figure 1: Emergence patterns for male and female Hairy Dragonfly *Brachytron pratense* at Ditchford Lakes and Meadows Local Nature Reserve, 2005. Daily exuviae counts are plotted for males and females as well as the cumulative percentage emergence.

be restricted to sedges with the larvae becoming more adventurous in their choice as the season progressed.

During early May, emergence usually occurred low down, on the thicker part of the leaf and typically at a height of 10–15cm above the water. Several exuviae were recovered with

the exuviae had slipped down after emergence was completed. Later in the season, emergence tended to be higher up the stem. Both of these observations suggest that emergence takes place at the point at which the larva obtains the best grip on the leaf, a point which becomes higher up as the vegetation grows. The implication is that larvae of *B. pratense* have a narrow range of leaf widths within which they can maintain a firm hold to support emergence.

Emergence was occasionally observed with the exuviae horizontal on the underside of the leaf. The weight of the larva on the early growth may simply cause the leaf to bend over, or this behaviour may be an adaptation to provide some protection against the variable weather in early May. Emergence was observed in most weather conditions including low temperatures, light frost, rain, and moderate wind. Corbet (1999) quotes low temperature as a factor inhibiting ecdysis; however on the frosty mornings when

B. pratense was observed emerging, emergence of the Four-spotted Chaser *Libellula quadrimaculata* L. was also recorded.

Adults typically emerged during the morning, starting around 0800h, and were highly synchronous. On 1 May 2005, for example, twelve *B. pratense* were observed at the same fully inflated, wings closed stage, by 0930h. Of the 77 emerging adults recorded at Ditchford Lakes and Meadows, only one was observed failing to complete ecdysis (G. Bentley, pers. comm.). This individual failed to molt and was later observed overrun by ants. One failure represents 1.3 per cent of the observed emerging population.

The average exuvia length at emergence was 39.6mm with a standard error of ±1.12mm. Males averaged 39.3±1.0mm and females 39.8±0.2mm. ANOVA tests gave $p=0.08$, indicating that the exuvia length between the sexes is not significantly different. Similarly no significant change was noted as the season progressed.

At Ditchford, emergence began on 30 April 2005, and was complete by 3 June. The earliest recorded emergence in the county was 29 April, in 2003. At Ditchford, of the total of 77 emergences noted, 50 per cent had emerged by 4 May (see Figure 1). Peak emergence was on 3 May.

Both sexes emerged at the same time and at the same rate. Females comprised 55 per cent and males 45 per cent, of the 75 exuviae that were suitable for sexing.

The first territorial males were recorded at the breeding site on the 17 May. Peak adult activity at the breeding site was 11–18 June, when in excess of 20 adults were recorded (males, copulating pairs and oviposting females). The last adults were recorded at Ditchford on 27 June, although at other sites records were obtained into mid July. The last flying adult recorded in the County was a female at Cransley Reservoir (SP 830781) on 14 July.

Conclusions

Emergence in early spring is a high-risk strategy for a large species like *B. pratense*. Variable weather conditions, including the potential for frosts, and low growth of emergent vegetation are two of the main difficulties this species must overcome. The favoured emergence support (sedges) are often the most abundant plant growth at this time of year and so may be the only support available with a suitable leaf width to ensure good grip, as well as being of a dense enough growth to offer some protection to the fragile emerging adult. It is possible that bulrushes and Common Club-rush are not favoured as the width of their stems may prevent the larva from maintaining a firm grip during emergence: in the case of bulrushes the stems could be too wide and, in the case of club-rush, too narrow. The low recorded height of emergence is probably an indication of the low growth of these plants. *B. pratense* copes well though, with 1.3 per cent of emergences encountered failing - a figure that if representative, shows a higher success rate than the 8.5 per cent to 15.8 per cent for the Emperor Dragonfly *Anax imperator* Leach (Corbet, 1999). Corbet refers to three classes of emergence failure: 1) failure to molt, 2) failure to expand and harden the wings and 3) predation. Emergence failures in Corbet's categories 2) and 3) were not observed among the populations studied.

Corbet (1999) illustrates emergence curves for the Southern Hawker *A. cyanea* (Müller) showing that males typically emerge 14 days before the females. This characteristic is common among summer emerging species, which have a relatively long flying season where opportunities for mating are not affected. However, in *B. pratense*, a spring species which has a relatively short lifespan, such an emergence interval between the sexes could reduce the opportunities for successful mating, hence the species exhibits synchronous emergence between males and females (see Figure 1).

Adults took around 18 day to reach maturity, by which time both sexes returned to the breeding site and copulation and oviposition began. From a study of emergence patterns and adult activity at water, the typical lifespan of an adult at Ditchford was estimated at between 25 and 35 days. To obtain a more accurate assessment, further studies are required, perhaps with marking experiments. The maximum flight season in Northamptonshire was recorded as 75 days. This compares with about 57 days in neighbouring Bedfordshire and approximately 84 days nationally (Cham, 2004).

Acknowledgements

I would like to thank Graham Bentley and Nigel Muddiman for providing additional records of emerging *B. pratense* at Ditchford.

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A study of the copulatory behaviour of three pairs of the Migrant Hawker *Aeshna mixta* Latreille in the wheel position

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Introduction

Following the realization that camcorder recording could yield new information about the behaviour of Odonata, for example the observation of wing clapping during copulation (Gibson, 2003), I made many more recordings of Odonata during the 2003 season. These included three uninterrupted recordings of pairs of Migrant Hawker *Aeshna mixta* Latreille in the 'wheel position' which are described in this article.

Methods

The equipment used has previously been described (Gibson, 2003). Each recorded sequence continued to beyond the end, or apparent end, of copulation. A detailed examination of these sequences has been made. Termination (of the wheel) is used here to refer to the disengagement of the female genitalia from the male secondary genitalia, recorded in two of the three sequences. All three recordings were made at Old Moor, South Yorkshire, now a reserve of the Royal Society for the Protection of Birds. For convenience of description and analysis, they are presented in reverse order of recording.

The circumstance of each recording was as follows:

Sequence 1 (S1). Recorded on 12 September 2003. When first seen, the pair were already in the wheel, with the male perched on the female inflorescence of a Bulrush (*Typha latifolia*). About 30 seconds were needed to position the tripod so as not to disturb the dragonflies. After termination the pair departed in tandem. An uninterrupted recording of 19min 7s was made up to termination.

Sequence 2 (S2). Recorded on 4 September 2003. A pair flying in the wheel were seen to land on a Bulrush stem. A period of about a minute was needed to find a good recording position for the tripod without disturbing the insects. The pair departed still in the wheel. The length of the uninterrupted recording, up to departure, was 13min 36s.

Sequence 3 (S3). Recorded on 3 September 2003. The pair were observed to fly in the wheel and land in vegetation in front of a hide from where recording began almost immediately. After termination the pair departed in tandem. The length of the uninterrupted recording, up to termination, was 19min 59s.

Analysis

Each sequence was played into an iMac computer using iMovie software, to become a video on the timeline. A spreadsheet was created to record: the timecode (in minutes, seconds and frames at 24 frames s^{-1}); the position of the female relative to the male; the thrusting or copulating rate of the male; activities such as abdomen touching of the male by the female, and wing fluttering; any further comments, including any occurrence of wing clapping. Thrusting rates were determined by counting the number of thrusts made by the male over a period of one to three seconds. All times were then calculated as minutes and decimal seconds before termination (for S1 and S3) or departure (for S2). By way of an example, a section of the spreadsheet for S1 is shown as Table 1. Recording behaviour in this way required frame by frame examination as some events were separated by very short intervals. The longest spreadsheet, for S3, has 180 timecode entries.

Table 1. Section of the spreadsheet recording copulatory behaviour in *Aeshna mixta* (Sequence 1). Time -prior to termination (min:sec); Position – see Figure 1; T.3 – female touching segment 3 of male; FHR – female head rocking; FWF – female wing flutter.

Timecode	Time	Position	Thrust rate	Activities	Comments
5:56:12	13:10.4	low	$0.5s^{-1}$	T.3 ends/FHR	
6:05:02	13:01.8	low	$0.5s^{-1}$	T.3	
6:10:03	12:56.7	low	$0.5s^{-1}$	T.3 ends	
6:14:08	12:52.6	high	nil		
6:16:20	12:50.1	high	nil		Wing clap
6:17:17	12:49.2	low	nil		for one frame only
6:17:18	12:49.2	high	nil	FWF	
6:18:02	12:48.8	low	$2.0s^{-1}$		no wing clap on second 'high'
6:29:10	12:37.5	low	$0.5s^{-1}$		
6:45:03	12:21.8	low	nil	T.3	
6:56:02	12:10.8	low	$0.2s^{-1}$	T.3 ends	

The completed spreadsheets were then examined for identifiable periods, for example when neither male or female showed any signs of movement, or when the male was making successive wing claps, or the female making a series of brief wing movements. Numbers of events within these periods were then counted. The data summary thus obtained is presented for S1, S2 and S3 as Table 2.

It was evident in all three sequences that the male held the female in three different positions or heights: low(the normal position), mid (a little higher than normal) and high (appreciably higher). An individual video frame for each position was identified, saved and printed. Tracings were then made from the prints to create Figure 1. The frames were taken from S1 because a broken stem intruding into the pictures (bottom right) shows precisely by how much the female is lifted. Figure 2, showing male abdomen

Table 2. Summary of data from filming sequences 1, 2 and 3 showing copulatory behaviour in Aeshna mixta. Time – time before termination (S1, S3) or departure (S2) (min:sec). Duration – period of activity. Recorded behaviours: FHR – female head rocking; T.3 – female (♀) touches segment 3 of male (♂); T.6 – female touches segment 6 of male; FAR – female abdomen rocking; FWF – female wing flutter; MWF – male wing flutter; high, mid, low, refer to position of the female (see Figure 1).

	Time	Duration	Male thrusts s^{-1}	Other behavioural observations
Sequence 1				
a	19:06.9	2:58.0	nil to 2.0; vigorous at 0.5	some FHR: alternate T.3 and T.6
b	16:08.9	0:03.0	–	♀ lifted to 'high', no wing clap
c	16:05.9	3:13.3	nil to 2.0	4 sustained T.3; 1 FWF
d	12:52.6	0:03.8	–	high – clap; v brief low, high – no clap
e	12:48.8	5:34.1	mostly low	1 sustained, 2 brief T.3
f	07:14.7	3:04.9	nil	frequent FAR not coincident with thrusting
g	04:09.8	2:44.7	nil	12 occasions of single FAR; MWF twice
h	01:25.1	1:25.1	nil	12 short bursts of T.3
Sequence 2				
a	13:36.2	0:29.2	2.0 then nil	♀ twice raised to mid position
b	13:07.0	1:04.7	nil to 2.0	6 wing claps
c	12:02.3	1:20.7	nil to 2.0	leg tangle first noted; 1 wing clap; 1 MWF
d	10:41.6	0:11.2	nil	♀ struggles; 2 wing claps
e	10:30.4	0:59.9	0.5 to 2.0	♀ struggles; raised 6 times to mid; 2 FWF
f	09:30.5	1:22.1	1.0 to 2.0 after clap	struggle, clap
g	08:08.4	4:18.7	low, vigorous to gentle	much ♀ leg movement
h	03:49.7	3:49.7	nil	5 FAR; 1 minor wing clap
Sequence 3				
a	19:58.9	2:27.5	0.7 to 3.0; 2.0 vigorous	♀ numerous touches on ♂ abdomen; frequent FWF; T.3
b	17:31.4	0:43.0	2.5 after wing clap	1 wing clap; T.3 at end
c	16:48.4	1:37.5	nil to 2.0; 0.4 vigorous	T.3; T.6 and FWF; some MWF
d	15:10.9	0:15.1		high, wing clap, then mid; 1 FWF
e	14:55.8	1:42.9	0.3 to 1.2	5 FWF; T.3 and T.6
f	13:12.9	0:23.0	nil; 1 vigorous at start	5 FWF; T.3 and T.6
g	12:49.9	4:00.9	mostly 2.0	3 MWF; FWF including doubles & triples; T.3; T.6
h	08:49.0	0:49.0	4 minor	only minor thrusts
i	08:00.0	2:53.5	13 singles	12 FAR between thrusts
j	05:06.5	2:58.6	nil	12 FAR; 1 T.6
k	02:07.9	2:07.9	nil	frequent FWF; T.3; T.6 – some continuous

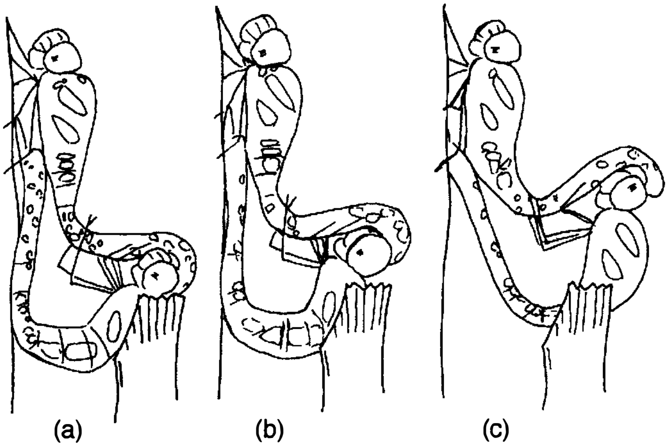

Figure 1. Position of female Migrant Hawker *Aeshna mixta* in the wheel. (a) low, (b) mid, (c) high.

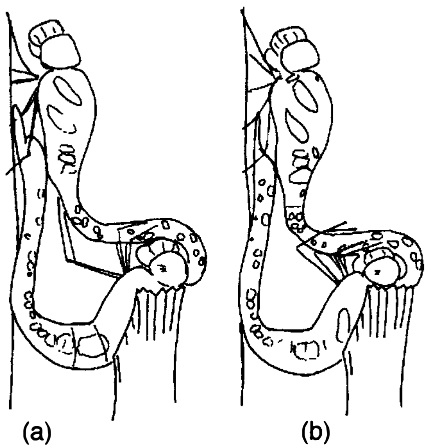

Figure 2. Female Migrant Hawker *Aeshna mixta* using her hind legs to touch the male abdomen. Touching (a) segment 3, (b) segment 6.

touching by the female, was produced in a similar manner. For clarity, the wings are omitted in Figures 1 and 2.

In order to identify the point of contact between the abdomens of male and female *A. mixta*, a frame was selected from S2, and used to create Figure 3. S2 was chosen because part of the recording was in greater close-up. The relatively low quality of prints from a domestic camcorder made identification of the segment boundaries difficult.

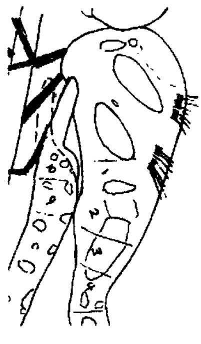

Figure 3. Contact point of female and male Migrant Hawker *Aeshna mixta*. The limit of movement of the female appendage is shown as dotted.

Observed behaviour

Some repeated behaviours were noted and entered into the spreadsheets as follows (abbreviations are those used in the tables):

T.3 – Female touching with her hind legs, the ventral side of abdominal segment 3 of the male (Figure 2a). The activity sometimes became a continuous drumming.

T.6 – Female touching with her hind legs, the dorsal side of abdominal segment 6 of the male (Figure 2b). Again, this could become continuous drumming. In Sequence 2, the right hind leg of the female becomes impeded by some loose strands of material from the Bulrush on which the pair are perched, preventing her from touching segment 6 of the male. She makes repeated, unsuccessful attempts to perform T.6.

FAR – Female abdomen rocking. The female appears to rock her abdomen at the point of genital contact: usually a single action. Movement at the point of contact is very slight but the accompanying movement of the female anal appendages is obvious (Figure 3). There is no visible external movement by the male but it is possible that internal movement of the male secondary genitalia causes movement by the female.

FHR – Female head rocking. The head of the female, together with the segments of the male abdomen in contact, make a rocking movement not apparently coordinated with any other movement.

FWF – Female wing fluttering, almost always lasting for two or three frames only.

MWF – Male wing fluttering, lasting for periods of the order of one second.

Wing clap – The female is raised into the high position (Figure 1c). The male then mantles the female head and thorax with his hind wings and brings his forewings sharply back in a 'clap' (Gibson, 2003).

Discussion

Sequences S1 and S3 are similar in length and general pattern, while S2 is about six minutes shorter and differs in behaviour, being influenced by the restriction to female leg movement described above, causing much struggling by the female. Also, the pair did not terminate the wheel before departing. However, three stages can be identified in all three sequences, as follows:

Stage I. A period of secondary genital thrusting in which the thrusting rate by the male varies from 0 to $3s^{-1}$ and the thrusts are occasionally vigorous. In Table 2, Stage I for each sequence is: S1 a–d; S2 a–f; S3 a–g.

Stage II. A period of slow and gentle secondary genital thrusting. In Table 2, Stage II for each sequence is shown as shaded: S1 - e; S2 - g; S3 - h–i.

Stage III. A period of no genital thrusting by the male, which precedes termination. In Table 2: S1 f–h; S2 h; S3 j–k.

Discussing these in reverse order, Stage III is the easiest to identify because it is a continuous period of no thrusting. The time periods of Stage III were, respectively, 7min 15s, 3min 50s and 5min 07s. The much shorter time for S2 may be because the struggles of the female caused modification to the normal sequence of events. In all three sequences there was female abdomen rocking (FAR) and in S1 and S3, abdomen touching (T.3, T.6). S2 again differed, with no abdomen touching, but there was a minor wing clap before departure in the wheel.

Stage II is identifiable as a phase in all three sequences, although the beginning times are less obvious. The time periods are estimated as 5min 34s, 4min 19s and 3min 43s. From the recordings it can be seen that thrusting by the male is much less vigorous as well as less frequent during this period. Only S3 shows abdomen rocking, and in all three sequences other observed behaviours are absent.

Stage I is identified here simply as the period preceding Stage II. All three pairs were already in the wheel when recording began and so a true time for each cannot be given, especially in the case of S2. Since the pair in sequence S3 were seen to arrive in the wheel, the time period of 11min 10s, deduced from the recording, may indicate what is normal for this species. It is difficult to see common patterns in the three recordings and S2 is particularly distorted by a whole series of wing claps, most likely associated with the struggle of the female. S3 has two claps in this period and in S1 the female is twice raised to the high position, but no clap is given. In all three, the thrusting rate is very variable, reaching 3 thrusts s^{-1} in S3. S1 and S3 show vigorous thrusting early on; S2 shows none but the early period in the wheel is the portion of Stage III not recorded for this pair.

According to Corbet (1999, pp. 516–518), a three stage sequence is well established for many Zygoptera, as exemplified by the Common Blue Damselfly *Enallagma cyathigerum* (Charpentier) for which Stage I lasts for *c.* 23min, with thrusting rate in the range

0.2–1.0s^{-1}, and is a period of sperm removal. Stage II is a brief transitory period with a rate of 0.25s^{-1}, devoted to sperm transfer. Stage III shows no detectable movement and is also short compared with Stage I. Corbet goes on to say that Anisoptera do not necessarily conform to this sequence: for example stages cannot be discerned for the Black Darter *Sympetrum danae* (Sulzer). He makes no reference to wheel stages for any Aeshnidae but does provide tabulated data for the maximum duration of the wheel in this family, with one genus showing 10min, another 15min, another 20min and two genera over 20min.

The durations of the stages observed here for *A. mixta* correspond well with the information for Zygoptera quoted by Corbet, but with Stage I taking a much shorter time, although still the greatest portion of the total time. The total time, although based on only two observations (19min 7s and 19min 59s, neither of which begin at wheel formation), fits with the longer periods reported by Corbet for Aeshnidae.

Corbet (1999, p. 517) presents a summary of the observations that were the basis of the stage analysis of *E. cyathigerum* referred to above. These include 'kicks by male', observed in Stages I and II and it is possible that these were wing claps, as I have observed for Blue-tailed Damselfly *Ischnura elegans* (Vander Linden) (Gibson, 2004), which occur in a fraction of a second and have not been identified previously by visual observation as wing claps. Also included is 'female grooming', observed in Stage III and it is possible that this was an action of similar function to the abdomen touching. I can find no reference of female touching of the male abdomen and it may not have been reported previously for any species of Odonata. The action is probably a signal to the male, but from the recordings could not be associated with any following actions. Similarly, the action called here 'female abdomen rocking' (FAR) does not appear to have been reported previously; it is associated only with Stages II and III.

The recordings also show that the point of abdominal contact, where the genitalia lock, is at the posterior end of segment 2 of the male and anterior end of segment 9 of the female. When the male thrusts, especially vigorously, there is noticeable displacement of the female abdomen, but during 'female abdomen rocking' (FAR) the male does not move (Figure 3).

Conclusions

1. The behaviour of *Aeshna mixta* in the wheel position can be categorized as being in three separate stages, based on the thrusting behaviour of the male: a more vigorous Stage I; a less vigorous Stage II; a passive Stage III.

2. The three stages of behaviour correspond in manner to those of many Zygoptera, especially *Enallagma cyathigerum*. The principal difference is that although Stage I is commonly the longest, it occupies a much lower proportion of the whole duration for *A. mixta*.

3. Touching by the female, with her hind legs, of the ventral side of segment 3 and the dorsal side of segment 6 of the male, occurs often in all three stages.

4. In Stage III the female abdomen moves in a rocking motion at the point of contact with the male. The movement is usually a single event and is apparently instigated by the female, there being no perceptible movement by the male.

5. Brief wing fluttering is a frequent activity of the female.

6. Over-activity by the female can induce a series of wing claps from the male.

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Population expansion of Small Red Damselfly *Ceriagrion tenellum* (Villers) in south-east Berkshire

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Summary

Since the early 1990s, as a result of a number of conservation measures, there has been a substantial increase in the population and local distribution of the Small Red Damselfly *Ceriagrion tenellum* in the area around Bracknell in south-east Berkshire. Here, details of the sites at which the species has recently been recorded are presented. To provide a context for the changed status of the species, historical records are discussed and the influence of habitat management considered.

Introduction

The Small Red Damselfly *Ceriagrion tenellum* (Villers) is a nationally scarce species. There are four main centres of population in Britain including Wales, the New Forest and Dorset, and Cornwall. The fourth important location is usually referred as the Surrey/Hampshire border region (Merritt *et al.*, 1996). The south-eastern corner of Berkshire is adjacent to the counties of Surrey and Hampshire, and this whole area was the subject of a comprehensive Odonata survey (Savan, 1977), carried out under contract to the Nature Conservancy Council. The report concluded that *C. tenellum* 'appears to be restricted to localities within, or close to, the Surrey county boundary, where suitable acid habitats are more common than in Berkshire or Hampshire'. The report also stated that the range of *C. tenellum* seemed to be contracting. Towards the end of the twentieth century, some dozen *C. tenellum* sites were known in Surrey (Follett, 1996), but several pre-1980 sites had been lost. Distribution maps, based on national surveys, show similar evidence of a long-term contraction of the Surrey/Hampshire population (Merritt *et al.*, 1996). It is therefore encouraging to be able to present data here which show a reversal of this trend. This article is an account of the population changes of *C. tenellum* since the early 1990s within that part of south-east Berkshire administered by Bracknell Forest Borough Council (BFBC), a Unitary Authority since April 1998, covering an area of 10,937 hectares (42.2 square miles) (see Figure 1).

During the past 15 years, 29 different species of Odonata have been recorded in the Borough (Table 1). Of these, 23 species are resident and breed annually and four, with no regular breeding records, are regarded as visitors. New records of oviposition in the Borough in 2005 were obtained for two species: the Small Red-eyed Damselfly

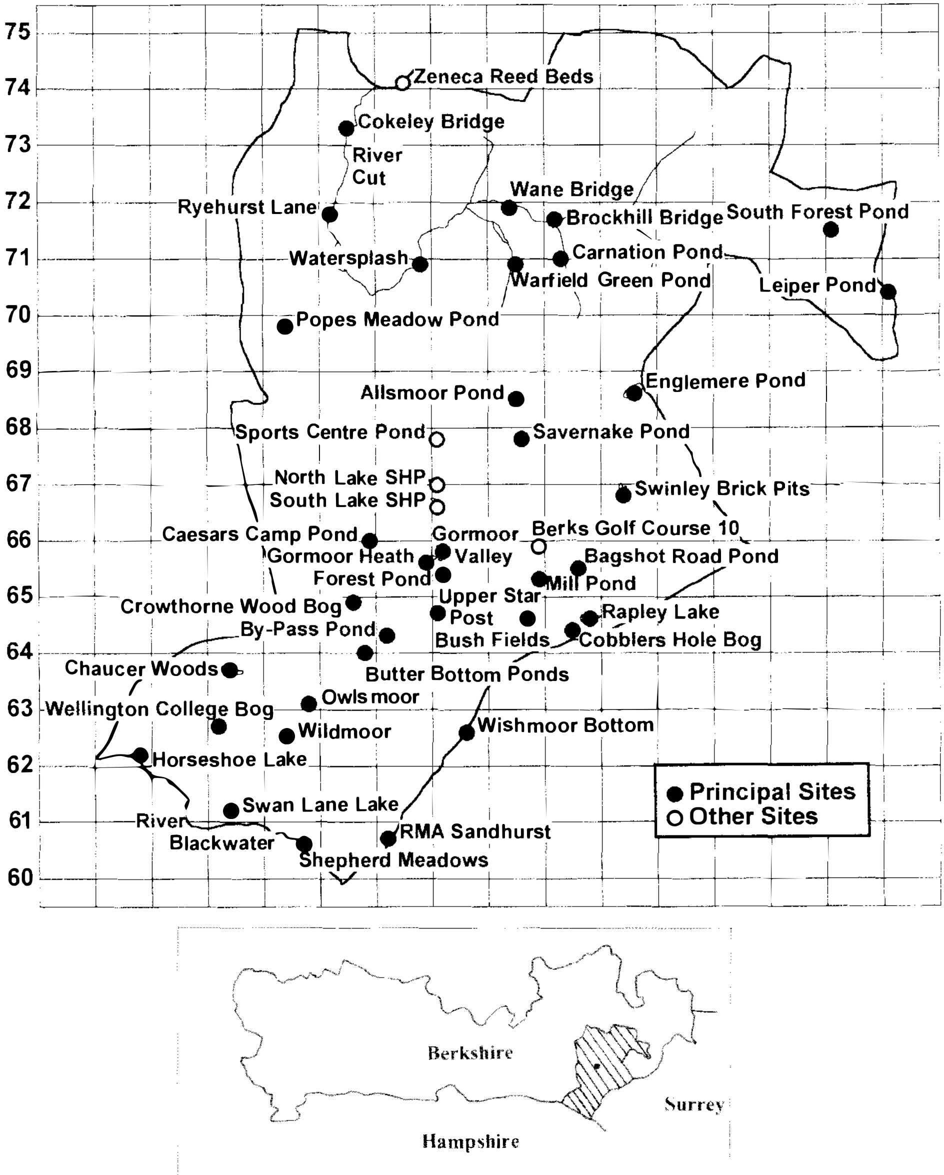

Figure 1. Map of the survey area showing the principal sites for Odonata. All the sites are within Bracknell Forest Borough, the boundary of which is shown. The location of the survey area in relation to the three counties of Berkshire, Hampshire and Surrey is shown separately. Bracknell town (shown dotted) is located *c.* 45km (28 miles) west-south-west of the centre of London.

Table 1. Odonata recorded in Bracknell Forest Borough

Resident species (23)	
Banded Demoiselle	*Calopteryx splendens* (Harris)
Emerald Damselfly	*Lestes sponsa* (Hansemann)
Large Red Damselfly	*Pyrrhosoma nymphula* (Sulzer)
Red-eyed Damselfly	*Erythromma najas* (Hansemann)
Azure Damselfly	*Coenagrion puella* (L.)
Common Blue Damselfly	*Enallagma cyathigerum* (Charpentier)
Blue-tailed Damselfly	*Ischnura elegans* (Vander Linden)
Small Red Damselfly	*Ceriagrion tenellum* (Villers)
Common Hawker	*Aeshna juncea* (L.)
Migrant Hawker	*Aeshna mixta* Latreille
Southern Hawker	*Aeshna cyanea* (Müller)
Brown Hawker	*Aeshna grandis* (L.)
Emperor Dragonfly	*Anax imperator* Leach
Golden-ringed Dragonfly	*Cordulegaster boltonii* (Donovan)
Downy Emerald	*Cordulia aenea* (L.)
Brilliant Emerald	*Somatochlora metallica* (Vander Linden)
Four-spotted Chaser	*Libellula quadrimaculata* L.
Broad-bodied Chaser	*Libellula depressa* L.
Black-tailed Skimmer	*Orthetrum cancellatum* (L.)
Keeled Skimmer	*Orthetrum coerulescens* (Fabricius)
Common Darter	*Sympetrum striolatum* (Charpentier)
Ruddy Darter	*Sympetrum sanguineum* (Müller)
Black Darter	*Sympetrum danae* (Sulzer)
Resident/Visitor species: Breeding activity observed 2005 (2)	
White-legged Damselfly	*Platycnemis pennipes* (Pallas)
Small Red-eyed Damselfly	*Erythromma viridulum* (Charpentier)
Migrant species and other occasional visitors (4)	
Beautiful Demoiselle	*Calopteryx virgo* (L.)
Scarce Blue-tailed Damselfly	*Ischnura pumilio* (Charpentier)
Hairy Dragonfly	*Brachytron pratense* (Müller)
Yellow-winged Darter	*Sympetrum flaveolum* (L.)

Erythromma viridulum (Charpentier), which is expanding its range nationally; and the White-legged Damselfly *Platycnemis pennipes* (Pallas), which was observed at a still-water site. The appropriate classification of these two species, either resident or visitor, will only be determined by future developments.

From about 1990 onwards, a number of important improvements to local habitats used by Odonata have taken place. These changes have had a major beneficial influence on the population of *C. tenellum* (and on other key species associated with these habitats, such as Keeled Skimmer *Orthetrum coerulescens* (Fabricius), Raft Spider *Dolomedes fimbriatus* (Clerck), Sundew *Drosera* sp., etc.). Some of the work has been done under contract to the site owners, and this has been augmented by a large effort from volunteer labour.

New ponds have been created and the habitat of some existing wetland sites has been enhanced in a variety of ways. In 1995, a small band of volunteers came together to form the Friday Conservation Team (FCT). This team has now completed ten years of work during the winter months, involving over 6000 man-hours of activity, mainly devoted to the improvement of heath and bog habitat used by nationally scarce Odonata. This paper reports in detail on the conservation measures taken on sites with historical records of *C. tenellum*, and on sites to which the species has spread in recent years.

Within Bracknell Forest Borough, the heathland habitat of particular importance to *C. tenellum* lies to the south and east of the town of Bracknell, with the southern limit of the survey area defined by the boundary with Hampshire along the River Blackwater, and the eastern limit by the boundaries with Surrey and the Borough of Windsor and Maidenhead. Parts of the western side of Windsor Great Park extend into Bracknell Forest Borough, and there are two important dragonfly sites in this overlap area. Some of the sites have statutory designations (SSSI and SPA) whilst others have local designation (Wildlife Heritage Site) or no formal designation.

Table 2. Sites in Bracknell Forest Borough where *Ceriagrion tenellum* has been recorded since 1990. The new sites are listed in order of colonization, location is provided by the six-figure British National Grid Reference.

Site	Grid Reference	Owner
1. Sites with records prior to 1990		
Swinley Brick Pits (3)	SU 904668	Crown Estate
Owlsmoor Bog (1)	SU 848630	County Wildlife Trust
Mill Pond (2)	SU 888653	Crown Estate
2. Sites to which *C. tenellum* has spread in recent years		
Crowthorne Wood Bog	SU 856649	Forest Enterprise
Bagshot Road Pond	SU 896655	Crown Estate
Gormoor Valley	SU 872658	Crown Estate
Englemere Pond	SU 907687	Crown Estate
Caesars Camp Pond	SU 859660	Crown Estate
Wishmoor Bottom	SU 876626	Ministry of Defence
Wildmoor Bog (1)	SU 844625	County Wildlife Trust
Bush Fields	SU 887646	Crown Estate
Cobblers Hole Bog	SU 895644	Crown Estate
Gormoor Heath	SU 869656	Crown Estate
South Forest Pond (3)	SU 941715	Crown Estate, Windsor Great Park
Leiper Pond (3)	SU 951704	Crown Estate, Windsor Great Park
By-Pass Pond	SU 862643	Crown Estate

Notes

1. Owlsmoor Bog and Wildmoor Bog are considered as separate sites here. Since 1997, these areas, together with Edgbarrow Woods, have been known collectively as Wildmoor Heath Nature Reserve.
2. Prior to 1990, records for Mill Pond were included by English Nature with those of Rapley Lakes SSSI.
3. Sites with restricted access.

Prior to 1990, there is historical evidence of *C. tenellum* at just three sites in the survey area: Swinley Brick Pits (1987), Mill Pond (1977–78), and Owlsmoor Bog (1950). Since 1993, when comprehensive surveys of Odonata in the Bracknell area were started, *C. tenellum* has been observed on 16 sites, of which three are the historical sites and 13 are new. The 16 sites, the conservation work carried out on these sites, and the data for *C. tenellum* will now be discussed. Summary information on the 16 sites is set out in Table 2. To the best of our knowledge no translocation of adults or larvae has taken place, and the colonization of all sites has been a natural process.

Historical data

A list of dragonfly sightings for east Berkshire drawn up by the curator of Reading Museum in 1990 contains three records for *C. tenellum*. These are: Crowthorne (1950), Sandhurst (1971–76) and Rapley (1978). It is difficult to relate with certainty any of these three records to specific sites considered in the present survey. The Crowthorne (1950) record is probably best represented by Owlsmoor Bog, the Sandhurst record is possibly from the grounds of the Royal Military Academy, large parts of which are currently out of bounds to the public due to military use, and the Rapley record might be for Rapley Lake or Mill Pond (probably the latter, see also below). During Savan's 1977 survey, several sites located within the current survey area were visited but no evidence of *C. tenellum* was found. Savan specifically noted that the species was absent from Englemere Pond.

English Nature (formerly Nature Conservancy Council) maintains records of dragonfly surveys for the area, and copies of those on file in 1992 were passed to the authors. The data from Savan (1977) are included in these records. Relevant records for four sites were provided: Englemere Pond, Swinley Brick Pits, Sandhurst to Owlsmoor Bogs and Heaths SSSI, and Rapley Lakes SSSI. In the present survey Rapley Lake and Mill Pond are treated as two distinct sites, but in former times English Nature included both sites within the single SSSI designated as Rapley Lakes. Some twentieth century records for the Mill Pond site were filed under the name Rapley Pond. There is no mention of *C. tenellum* in the records of Vick for 1973–77 and Savan (1977) for Englemere Pond. Similarly, survey results for Swinley Brick Pits from Savan (1977) and Vick, dated 1979, make no mention of *C. tenellum*. However, Rees found *C. tenellum* at Swinley Brick Pits in 1987, reporting the status of the species as local. There is no mention of *C. tenellum* in the species list for the Sandhurst to Owlsmoor Bogs and Heaths SSSI (undated management plan). The records for Rapley Lakes SSSI are mixed. Stubbs, Chandler and Hammond only recorded five species of Odonata, but not *C. tenellum*, when they visited Mill Pond (identified by grid reference) in August 1975. However, Vick recorded *C. tenellum* at Rapley Lakes SSSI in 1977–78. In the present survey (1993–2005), *C. tenellum* has been recorded regularly at Mill Pond but not at all at Rapley Lake, so the likelihood is that the Vick record for 1977–78 relates to Mill Pond.

In summary, the records from English Nature contain historical evidence of the presence of *C. tenellum* at Swinley Brick Pits (1987) and at Mill Pond (1977–78), and the Reading Museum record for Crowthorne (1950) is probably best interpreted as relating to Owlsmoor Bog. These data give no indication of population size nor evidence of breeding.

Dragonfly survey results

The records of *C. tenellum* in the survey area are set out in Table 3, listing new sites in the chronological order in which records were first obtained. The data are presented using the BDS alphabetical notation to indicate the maximum number of flying adults observed on any one site visit in a given year and breeding status is indicated where observed. The first record of *C. tenellum* in the 1990s was of a singleton at Mill Pond in 1993. Although Swinley Brick Pits and Owlsmoor were searched in 1993 and 1994, it was not until 1995 that the species was recorded at these two sites. In that year a single male was also observed at Crowthorne Woods Bog. In later years *C. tenellum* started to be found at other sites until, by 2005, records had been obtained at thirteen new sites for which no historical record existed. It is of interest to note that, in addition to the data listed in Table 3, a single male was recorded during 2004 in the garden of one of us (DS), at grid reference SU 833618.

Summary statistics are presented at the foot of Table 3. By 2005, the aggregate 'over years' total for sites where flying adults have been observed since 1993 is 16 with evidence of breeding observed at 11 sites. Every year, one or more sites where *C. tenellum* has been recorded in a previous year yields a zero return. The total sites at which *C. tenellum* was recorded in a given year reached its highest level in 2005, with records from 14 sites. In 2005, evidence of breeding was obtained at 6 sites, but this figure fell short of the 8 records obtained in 2003. Whether the species will breed successfully at all the sites at which it is recorded remains to be seen. However, as will be discussed, it appears that some sites are not ideally suited to the species, and this trend is unlikely to materialize.

The present study demonstrates that *C. tenellum* has, in recent years; spread to a range of different sites, including long-established ponds (e.g. Englemere Pond), newly-created ponds (e.g. Caesars Camp Pond) and sites where the habitat was unsuitable prior to the survey period (e.g. Gormoor Valley). Flourishing breeding colonies are now established at Crowthorne Wood Bog and Caesars Camp Pond (Table 3). The records for Wildmoor Bog also suggest it has been successfully colonized. At Englemere Pond, colonization has been followed by decline, and the same may be happening at Bagshot Road Pond. In the past few years, adults have been seen consistently at Gormoor Valley and Bush Fields but, with few breeding records, colonization remains unproven. The recent records at Leiper Pond look highly encouraging. For the remaining five sites, including the new record for By-Pass Pond in 2005, it is too early to decide whether or not a stable colony has been established.

Table 3. Abundance of *Ceriagrion tenellum* recorded at sites in Bracknell Forest Borough. BDS notation is used (A: 1 individual; B: 2–5; C: 6–20; D: 21–100; E: 101–500; F: 500+). Where evidence of breeding was recorded, this is noted (in ranking order of importance) as exuviae (ex); teneral (te); oviposition (ov) and copulation (co). The highest ranked breeding activity recorded in a year is shown. Other symbols are: site visited during flight season and no *C. tenellum* recorded (0); site not visited during flight season (x); and site habitat unsuited to *C. tenellum* prior to management (#).

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Swinley Brick Pits	0	0	D(co)	D(co)	D(co)	D(co)	E(te)	D(co)	D(ov)	F(co)	F(ex)	E(ov)	D(te)
Owlsmoor Bog	0	0	B	B	B(co)	B(co)	D(co)	D(co)	C(te)	D(te)	D(te)	C(te)	C(te)
Mill Pond	A	0	0	B(co)	A	A	A	0	A	B	A	B	C(te)
Crowthorne Wood	0	0	A	0	0	0	A	A	B	C(co)	C(co)	C(co)	D(te)
Bagshot Road Pond	#	#	#	#	A	0	0	0	A	B	B	C(co)	B
Gormoor Valley	#	#	#	0	0	A	0	A	0	A	B	B(ov)	B
Englemere Pond	0	0	0	0	0	0	B(co)	0	C(co)	B(te)	D(co)	A	0
Caesars Camp Pond	#	#	0	0	0	0	B	C(te)	C(ov)	C(co)	C(co)	D(te)	C(te)
Wishmoor Bottom	x	x	x	x	x	x	A	x	x	0	0	0	0
Wildmoor Bog	#	#	#	#	#	0	0	0	A	C(co)	C(co)	B	C(te)
Bush Fields	#	#	#	#	#	0	0	0	0	A	B(te)	B	B
Cobblers Hole Bog	#	#	#	#	0	0	0	x	0	0	A(te)	0	A
Gormoor Heath	#	#	#	#	0	0	0	0	0	0	A	0	B
Leiper Pond, WGP	x	x	0	x	0	0	0	0	x	x	0	B	C
South Forest Pond, WGP	x	x	x	x	0	0	0	x	x	x	x	A	A
By-Pass Pond	x	0	0	0	x	0	0	x	x	x	x	0	B
Aggregate number of sites since 1993													
Flying adults recorded	1	1	4	4	5	6	9	9	10	11	13	15	16
Breeding evidence	0	0	1	2	3	3	4	5	5	7	9	11	11
Number of sites recorded within a single season													
Flying adults recorded	1	0	3	3	4	4	7	5	8	10	12	12	14
Breeding evidence	0	0	1	2	2	2	3	3	4	6	8	6	6

Conservation and management measures

The management work carried out since about 1990 on the 16 sites considered here is summarized in Table 4. Some further details follow, starting with the sites of historical importance.

Swinley Brick Pits: This is a large site which, as its name suggests, was formerly used for brick-making. At a rough estimate, the habitat suited to dragonflies is now scattered over 10 hectares. It was not always thus. Up to 1995, as a result of plantation forestry and natural regeneration, large parts of the site were shaded by dense Pine (*Pinus* sp.) and Rhododendron (*Rhododendron ponticum*), with some areas of open water. *C. tenellum* was confined to a small system of ponds entirely surrounded by mature trees. In 1995, contractors were deployed by the Crown Estate to remove nearly all the mature pines and rhododendron, transforming the site into a high quality open heathland habitat. For the

Table 4. Habitat management on sites for *Ceriagrion tenellum* in Bracknell Forest Borough.

Site	Nature of conservation work	Date
1. Sites with records of *Ceriagrion tenellum* prior to 1990		
Swinley Brick Pits	Extensive removal of rhododendron and mature pine trees	1995
	Creation of a bund to control water level at exit from site	1999
Owlsmoor Bog	Introduction of cattle increased number of bog pools	1990
Mill Pond	Stepped log dams introduced in drainage ditches along Mill Ride	1980s
2. Sites to which *Ceriagrion tenellum* has spread in recent years		
Crowthorne Wood Bog	Removal of pine, birch and rhododendron from valley mire	1989–90
	Clear fell of pine trees around bog	2002
	Creation of a dam to control water level at exit from site (FCT)	2002–03
	Construction of satellite pond (FCT)	2003–04
Bagshot Rd Pond	Removal of rhododendron and deepening of pond	1996–97
Gormoor Valley	Removal of pine, birch and rhododendron from valley mire, plus pool creation (FCT)	1995–96
Englemere Pond	Removal of birch scrub to create dry heathland corridor	1990s
Caesars Camp Pond	Pond created by contractors for Crown Estate	1994
	Clear fell of pine trees around bog	2002
	Construction of satellite pond (FCT)	2004–05
Wishmoor Bottom	Pond creation	2003
Wildmoor Bog	Creation of ponds, dams and sluices to retain water (FCT)	1998–99
Bush Fields	Removal of pine, birch and rhododendron from valley mire, plus pool creation (FCT)	1997–98
Cobblers Hole Bog	Removal of pine, birch and rhododendron from valley mire, plus pool creation (FCT)	1996–97
Gormoor Heath	Removal of pine, birch and rhododendron from valley mire, plus pool creation (FCT)	1996–97
South Forest Pond	Enlargement, deepening and clearance of existing pond	1995–96
Leiper Pond	Clearance of existing pond	*c.* 1996
By-Pass Pond	Pond created by contractors for Crown Estate	1992

first time for many years the numerous bog pools and runnels were exposed to sunlight and the *C. tenellum* pools were now connected by a network of other ponds. Further improvements took place in 1999. A large bund was constructed to control the way in which water left the site, raising the water level at exit and thereby creating a much larger area of open water than had hitherto existed towards the north of the site. Table 3 shows that the conservation measures undertaken in 1995 had a dramatic effect on the population of *C. tenellum*. In subsequent years their numbers increased and they progressively dispersed over the entire site from the initial centre of concentration.

Owlsmoor Bog: House and road building in the second half of the twentieth century considerably reduced the amount of wet heathland south of Crowthorne. In the 1980s, Owlsmoor Bog was gradually drying out as a consequence of these developments. With the introduction of cattle to the site in the early 1990s this trend has been reversed. The trampling action of the stock has created many surface pools on the wet heath. Grazing also controls the growth of Purple Moor-grass (*Molinia caerulea*) which was previously smothering the wetland habitats. Both of these factors are contributing to an improvement of the flora and fauna on the site and the numbers of *C. tenellum* have steadily increased over the years (Table 3), although the increases have been less dramatic when compared to those at Swinley Brick Pits.

Mill Pond: The simple expedient of damming drainage ditches in the 1980s improved water retention along Mill Ride. It is here that *C. tenellum* is currently seen, although it has not been recorded around the pond itself, parts of which are difficult to survey. Mill Pond provided the first record of *C. tenellum* in the survey period, and there have been consistent sightings of flying adults there in recent years. Yet, numbers have always been low, always in single figures, and breeding activity has only rarely been observed. The consistency of the records over the years is indicative of a small stable breeding colony. However, it is possible that the few adults observed each year may have dispersed from the much larger population that exists at Swinley Brick Pits.

The increased population size at Swinley Brick Pits and Owlsmoor Bog, together with the historical records for the two sites, suggests that it is probable (although unproven) that these two sites are the sources from which *C. tenellum* has dispersed to other sites in the area.

Sites with new records for *Ceriagrion tenellum*

Englemere Pond and Bagshot Road Pond are two long-established ponds. Englemere Pond is almost entirely surrounded by pine trees and has an extensive reed bed. There are also areas of low level vegetation that fringe the pond, including grasses, rushes, and Marsh St John's-wort (*Hypericum elodes*). Here no major changes to the habitat have been made in recent years, although routine maintenance involves Willow (*Salix* sp.) and Birch (*Betula* sp.) scrub being periodically cut back to prevent encroachment. During the 1990s, Birch and Pine clearance led to the creation of small corridors of dry heathland leading away from the pond. This shallow pond has shown significant drawdown in some years, almost drying completely in 1990. At Bagshot Road Pond, Rhododendron had completely smothered the margins and a large part of the open water, rendering this woodland pond unattractive to dragonflies. The removal of the Rhododendron together with general clearance work to give the pond greater depth, undertaken by contractors working for the Crown Estate during 1996–97, has allowed a range of vegetation more suited to the requirements of dragonflies to develop. Caesars Camp Pond and By-Pass Pond are excellent examples of new ponds, dug by contractors using mechanical excavators, which have been colonized by a wide range of Odonata.

Large parts of the area south of Bracknell are covered by rotationally felled commercial conifer plantations. Several valley bogs – Gormoor Valley, Gormoor Heath, Bush Fields, and Cobblers Hole Bog – have always been unsuitable for timber production and so were never planted up. However, over a prolonged period, natural regeneration had extensively covered these bogs with Rhododendron, Birch and Pine. In recent years, large parts of all these sites have been cleared by the FCT to yield high quality bog and mire habitats, with vegetation including *Sphagnum*, Bog Asphodel (*Narthecium ossifragum*) and Cottongrass (*Eriophorum* sp.). Once a site had been cleared, small areas of open water were created in one of two ways: either by removing and stacking *Molinia* tussocks to form a 'living' dam, or by winching out the root plates of cut down trees. Crowthorne Woods Bog is another valley bog which was partially cleared around 1989–90, just prior to the onset of the current survey.

Prior to recent conservation work, Wildmoor Bog used to be wet in winter but would dry out in summer. It has benefited from work to manage the water flow, including the construction of dams, bunds, spillways and weirs, and the creation of additional ponds. The volume of water retained on site throughout the year has been increased significantly, with the creation of large areas of open water and bog/marshland. A small pond had existed for many years at Wood Pond, South Forest (referred to here as South Forest Pond). During 1996–97, its area was considerably enlarged by contractors and deepening and clearance work were also carried out. Leiper Pond is another established site that was also subject to clearance work in the 1990s.

The Wish Stream at Wishmoor Bottom is the county boundary separating Berkshire from Surrey. Within the survey area, to the north of the stream, there is an area of wet heathland. Some natural bog pools exist, but small areas of open water have also been created, apparently by military activity where tank tracks have been left. In 2003, some effort was made by the FCT to retain more water in these areas, but this work has not proved very successful due to continuing military use of the area.

Further work by the FCT in recent years has led to the construction of satellite ponds at Crowthorne Woods Bog and Caesars Camp Pond. The main drainage ditch leading from Caesars Camp Pond was dammed in 2004–05 to create a new pond approximately

150m downstream from the main pond. At Crowthorne Woods, a drainage ditch some 200m to the west of the bog was dammed in 2003–04 to create an area of open water.

Discussion

At several sites, an initial record of *C. tenellum* has been followed by a gap of one or more years before the species has been seen again (see Table 3). This might be simply explained by a lone adult reaching the new site with no breeding taking place in that year. However, there might be an alternative explanation. Due to the shape, size, coloration and flight style of *C. tenellum*, adults are not very conspicuous in the habitat they occupy. When present at low densities, such as when colonizing a new site, adults may be overlooked and under-recorded. Adults are most obvious at higher densities when males interact and mating pairs are formed.

The months of August, September and October 2003 were exceptionally hot and dry and large areas of Swinley Brick Pits normally covered by shallow water dried out completely. Similarly, at Wildmoor Bog the water level dropped leaving areas of mud but little open water. In 2004, the counts at Swinley Brick Pits and Wildmoor were substantially down on the previous year, but recovered in 2005 to suggest that the *C. tenellum* populations at these sites are able to withstand such conditions. At Englemere Pond this may not be the case. When the water is at its normal level, parts of the margins are vegetated by an abundance of Marsh St John's-wort and this is particularly popular for oviposition by Odonata. The hot weather of 2003 caused the water level of this large shallow pond to drop (as also occurred in 1990), leaving large parts of the margin out of contact with the Marsh St John's-wort and turning the pond into a large muddy puddle. In 2004, the count was dramatically down on the previous summer and in 2005 no *C. tenellum* were recorded at Englemere, despite several detailed searches, suggesting that the drying out of the site in 2003 had been responsible for the reduction in numbers the following year. During 2005, the water level at Bagshot Road Pond dropped significantly, affecting particularly that part of the site favoured by *C. tenellum*. It remains to be seen whether the species can retain a viable colony at the site. There is, however, evidence that *C. tenellum* has some tolerance of adverse conditions. In September 2002, at Crowthorne Woods, standing water was released from the bog during timber extraction from the adjacent woods. A new dam and spillway were constructed by the FCT during the winter of 2002–03, resurrecting the area of open water. The level of dragonfly activity at the site during the summer of 2003 was high, 17 species being recorded with a high level of breeding success. This experience demonstrated the ability of dragonfly larvae to survive in mud and amongst the moist roots of vegetation. The numbers of *C. tenellum* were slightly up on the previous year.

Table 5 suggests possible relationships between new sites and source sites, assumed to be Swinley Brick Pits or Owlsmoor Bog. Approximate distances from source to receiving site are given, and an estimate is made of the number of years delay before *C. tenellum*

Table 5. Colonization of new sites for *Ceriagrion tenellum* in Bracknell Forest Borough. Sites are grouped according to their proximity to source sites, assumed to be Swinley Brick Pits and Owlsmoor Bog. The distance stated is from either Swinley Brick Pits or Owlsmoor, whichever is nearer. The delay before colonization is calculated by subtracting either 1994 or the year in which the site was first considered suitable for colonization from the year in which *C. tenellum* was first observed.

Site	Nearest Source	Distance (km)	Year Site Suitable	First Sighting	Delay (years)
Crowthorne Wood Bog	Owlsmoor	2.1	1994	1995	1
Gormoor Valley	Owlsmoor	3.5	1995	1998	3
Caesars Camp Pond	Owlsmoor	3.2	1994	1999	5
Wishmoor Bottom	Owlsmoor	2.8	1994	1999	5
Wildmoor Bog	Owlsmoor	0.7	1997	2001	4
Gormoor Heath	Owlsmoor	3.4	1996	2003	7
By-Pass Pond	Owlsmoor	2	1994	2005	11
Bagshot R d Pond	Swinley	1.7	1996	1997	1
Englemere Pond	Swinley	1.8	1994	1999	5
Bush Fields	Swinley	2.8	1997	2002	5
Cobblers Hole Bog	Swinley	2.7	1996	2003	7
South Forest Pond	Swinley	6.0	1994	2004	10
Leiper Pond	Swinley	5.9	1994	2004	10

arrived at the receiving site. There is no discernable relationship between colonization delay and distance for the seven sites in proximity to Owlsmoor Bog. However, linear regression analysis indicates that there is a significant relationship between colonization delay and distance from source for the six sites in proximity to Swinley Brick Pits ($p<0.05$). The appearance of *C. tenellum* at Leiper Pond and South Forest Pond in 2004 was unexpected and show that the species can disperse over considerable distances (as much as 6km).

Habitat quality appears to be critical in determining the distribution of *C. tenellum*. There are two characteristics which all the 16 sites considered here have in common. These are: a) grassy areas close to the water, especially *Molinia*, in which the adults can perch, move about and mate, and b) shallow margins with low-growing vegetation suitable for oviposition. There are numerous sites within the survey area, including woodland ponds and balancing ponds, which lack these characteristics and are not used by *C. tenellum*, but they do have good populations of other species of Odonata.

An indication of the significance of the population changes discussed in this article is provided by records in the ORS/DRN database over the period 1990 to 2004, for the three vice-counties Berkshire (VC 22), Surrey (VC 17) and North Hampshire (VC 12). Over the 15 years, *C. tenellum* records were submitted for some 20 sites in Surrey, 15 in North Hampshire and 16 in Berkshire. If, however, the data are analyzed in terms of the

5 year periods 1990–94, 1995–99, 2000–04, then significant trends are evident. For the period 1990–94, records for *C. tenellum* were submitted for some nine sites in Surrey, seven in North Hampshire, and just one in Berkshire. For the period 2000–04, the corresponding figures were: six in Surrey, ten in North Hampshire, and 14 in Berkshire. The large rise in Berkshire sites is almost entirely accounted for by the sites featured in this article.

C. tenellum appears to be vulnerable to two separate threats. First, population loss can be caused by various forms of long-term habitat degradation, an example of which is the invasion of Birch, Pine and Rhododendron on to bogs and mires. Second, a single summer of hot weather can cause a site to dry out with immediate damaging consequences to dragonfly populations. The present study has demonstrated that these effects can be mitigated by providing a network of suitable sites which are within the local dispersal range of the species (here shown to be up to about 6km), thus allowing movement between sites to take place. Appropriate habitat management targeted to enhance breeding ponds/pools, and the adjacent terrestrial habitat, has been shown to play an important part in the conservation of *C. tenellum*. The conservation work reported here has allowed the development over an area of south-east Berkshire of a more dispersed metapopulation from the previously vulnerable remnant colonies at Swinley Brick Pits and Owlsmoor.

Acknowledgements

Map 1 was constructed using DMAP, courtesy of Dr Alan Morton. The habitat management work carried out by the Friday Conservation Team (FCT) would not have been possible without the help and encouragement of various bodies and individuals. It was at Gormoor Valley, on Crown Estate land, that it all began in 1995, and special thanks are due to Steve Searle, Forest Manager, for his continued support of the team's efforts over the past ten years. The more recent cooperation of Forest Enterprise, in particular Nick Hazlitt, at Crowthorne Woods and the Ministry of Defence at Wishmoor Bottom is gratefully acknowledged. The Countryside Ranger Service at Bracknell Forest Borough Council, the Conservation Officers of the County Wildlife Trust, and individual staff members at English Nature have all contributed in various ways. A special word is due to present and former colleagues with whom we have worked as members of the FCT: David White, Charles Hill, Peter Knipe, David Lloyd, Chris Rush, Colin Gray, Ted Green. Our combined experiences during many hours of toil under treacherous conditions have given rise to the alternative name for the FCT – the 'Bracknell Brownsocks'.

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Book review

The Dragonflies of Europe (revised edition)
Harley Books, Martins, Great Horkesley, Colchester, Essex CO6 4AH (2004);
17 × 23 cm; 308 pp.; 513 text figures; 219 colour figures
£30.00 (soft cover). ISBN 0 946589 75 5
R. R. Askew

Dick Askew's *The Dragonflies of Europe* has been the outstanding English text on European dragonflies since it was first published in 1988. The original edition included a brief but authoritative account of dragonfly taxonomy, morphology, biology and ecology, which provided a useful contextual background. The bulk of the book was devoted to the identification of the European Odonata and easy-to-use keys to the adults and larvae of each species facilitated this. Each of the 114 species of European Odonata then recognized were described in detail, the descriptions being supplemented by high quality, accurate line-drawings of the important morphological features necessary to distinguish each species. Most of the species were also featured within the 29 plates of excellent colour paintings. Notes on distribution, together with distribution maps, full synonymy, biological characteristics and flight period, completed each species account.

Work on European dragonflies has not stood still since 1988 and the time is now ripe for a new edition. The book has been brought up to date by the addition of a new colour plate and nine supplementary pages, including nine new line drawings. These provide us with brief descriptions of 10 species that have recently been found in Europe, including *Somatochlora borisii*, which was described from Bulgaria as a new species in 2001. The nomenclature has been updated for nine species. An account of changes in distribution, probably in response to climate change, has been added which provides an interesting European context to the dramatic shifts in the distribution of Odonata we have been witnessing in Britain during the last 15 years. New national or significant regional distribution records are also provided for many species.

The revised edition comes in a soft cover and the pages have been reduced in size to about 17 × 23 cm. These new features make the book much more handy to use than the original, although the print is now rather small. *The Dragonflies of Europe* is not a field guide; rather it is an authoritative identification manual to be used at the laboratory bench. Since its original publication I have found the book invaluable for identifying the adults and larvae of the European dragonflies and refer to it frequently. I look forward to using the revised edition for many years to come.

Steve Brooks

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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. 1983. *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.

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

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