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The Journal of the British Dragonfly Society, published twice a year, contains articles on Odonata that have been recorded from the United Kingdom and articles on European Odonata written by members of the Society.

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Cover illustration: Larva of Somatochlora metallica. Photograph by Steve Cham.

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    - The following terms are used: `exuvia' for cast skin (plural: `exuviae'); `larva' (instead of `naiad' or `nymph'}; `prolarva' to designate the first larval instar.
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            - Smith, E.M. & Smith, R.W.J. 1995. *Somatochlora metallica* in Scotland. *Journal of the British Dragonfly Society* **1:** 37-38.
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The status of *Somatochlora metallica* (Vander Linden) (Brilliant Emerald) in Scotland

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Abstract

The distribution of *Somatochlora metallica* (Brilliant Emerald) in Scotland is restricted to two well separated areas where it breeds primarily in upland lochs and lochans. It was formerly considered to be present in three separate areas but, since 2012, the number of known sites for *S. metallica* in Scotland has doubled, resulting in an expansion of its known range in this country. A number of these sites link the former main breeding areas of Loch Bran and Loch Affric in Inverness-shire. The other cluster of sites is in Argyll. Also, as a result of increased recorder effort, further observations on habitat preferences and breeding behaviour are presented.

Introduction

Somatochlora metallica (Vander Linden) (Brilliant Emerald) is widespread across Europe and is relatively common in Alpine areas where the sites are regarded to be similar to those in Scotland (Smith & Smith, 1995). It has a disjunct distribution in Britain and is classed as vulnerable in the British Red Data book (Daguet *et al*., 2008). There are two distinct populations in Britain, in the Highlands of Scotland and in south-east England (Cham *et al.*, 2014; Cham, 2022).

Until recently, *S. metallica* was known from three separate areas in Scotland (Smith & Smith, 1995, Batty, 2013, Cham *et al*., 2014), one in Argyll and two (Loch Bran and Glen Affric) in Inverness-shire. Since 2012, additional recording effort for this species has increased the range and number of known sites, including a number which link the Loch Bran and Glen Affric areas so that Inverness-shire sites can now be regarded as one population.

This paper examines British Dragonfly Society records (British Dragonfly Society, 2021; i record, 2021) and recent survey work in Scotland to give additional insight into the distribution, behaviour and habitat of this elusive

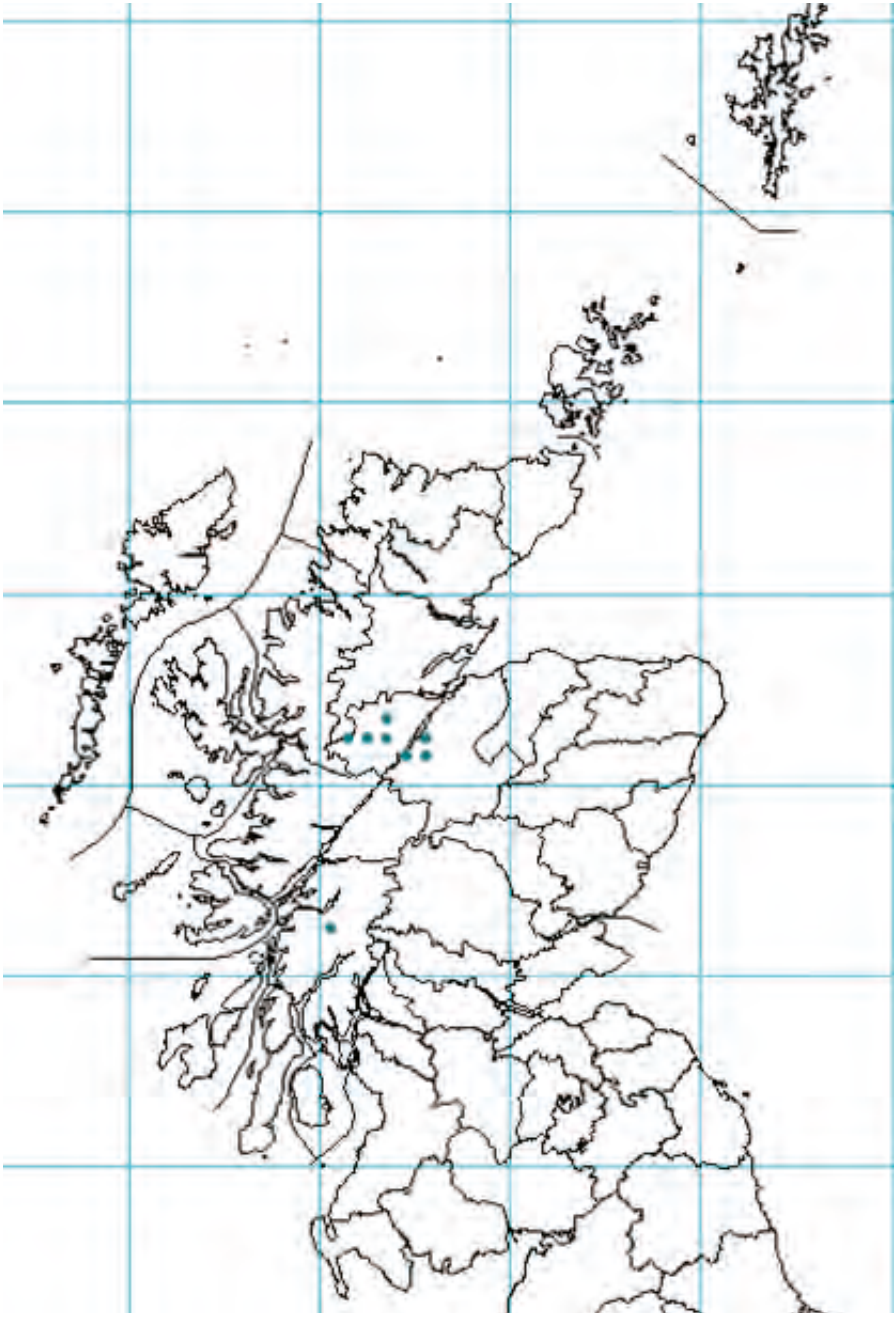

Figure 1. Distribution of *Somatochlora metallica* pre-2000 at a 10km² square resolution. Aditsite map using records from the British Dragonfly Society Data Base (2020).

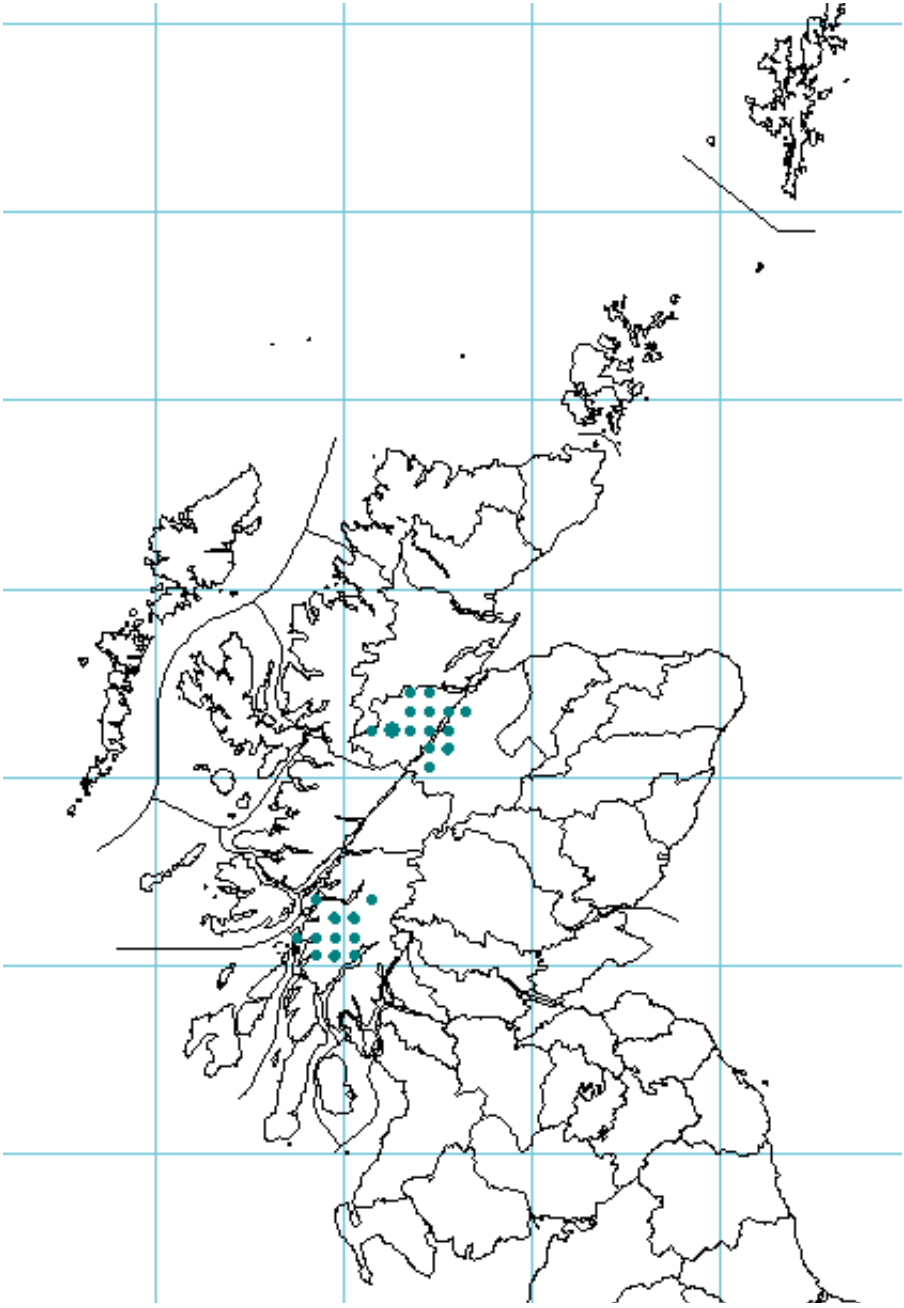

Figure 2. Distribution of S*omatochlora metallica* 2000-2020 at a 10km² square resolution. The larger circles show the sites which have more records. Aditsite map using records from the British Dragonfly Society Data Base (2020).

dragonfly (Cham *et al*., 2014).

Sites

In total the number of hectads in Scotland where *Somatochlora metallica* has been recorded has increased considerably from eight pre-2000 to 25 in 2020 (Figs 1, 2) and the number of sites from 31 to 109.

Argyll

In Argyll (Fig. 3) there are 33 sites for *Somatochlora metallica* compared with just two known sites pre-2000. The number of hectads (10 km²) has increased from one to 11.

The upland lochans on both sides of Loch Awe have a strong population of *S. metallica* (Batty, 2013). The known area now stretches from Ford northwards to beyond Oban for 35 km. Since 2013 additional sites have been discovered and the population now extends west towards the coast for 25 km. Most interestingly, larvae have been found in Loch Ederline, just south of Loch Awe, which is only 38 m a.s.l. (above sea level). The most northerly site is at Lochan Uaine on Beinn Donachain, 17 km to the northeast of the nearest other known site. With the exception of this site the lochan groups are rarely more than about 10 km apart (Fig. 3).

In Argyll most sites are fairly exposed hill lochs (Batty, 2013) and some are in open moorland or grassland, with undulating topography providing some shelter. Above Loch Awe there are extensive conifer plantations which range from newly planted trees to mature forestry. The original site, Loch a Chriondoire, would have been in open moorland when discovered by J.K. Morton in 1922 (Smith & Smith, 1995) but the area has since been forested. *Somatochlora metallica* is still recorded at this site.

Inverness-shire

In Inverness-shire (Fig. 4) there are 76 sites for *Somatochlora metallica* compared with 29 known pre-2000, the number of hectads increasing from seven to 14.

The population in Inverness-shire now extends from near Beauly in the north, for about 40 km south to the original sites in Glen Affric; then from Glen Strathfarrar in the west, eastwards for 23 km to the east of Loch Ness. The lochans can be up to 10 km apart, but some are in a group within 1 km of each other. The

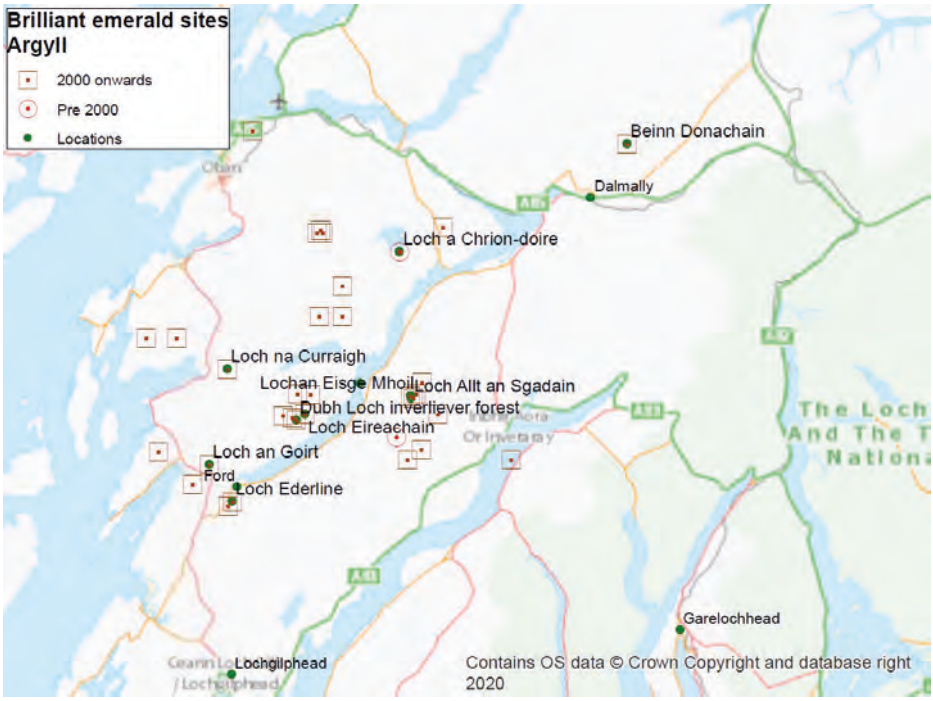

Figure 3. The location of *Somatochlora metallica* sites in Argyll, west Scotland. Pre 2000 sites are those first recorded between 1900 and 1999 and they all continue to be viable sites. 2000 onwards sites were first recorded between 2000 and 2021.

nearest lochans of the main Loch Bran group on the east side of Loch Ness are as little as 3 km from ones on the west side (Fig. 4).

Most of the original sites at Glen Affric are within the remnants of the old Caledonian pine forest and *S. metallica* continues to breed here. East of loch Ness, many of the sites are on a 3 km wide afforested rocky ridge centred around Loch Bran. The known area is now more extensive, covering 35 km, virtually the length of Loch Ness. In this area there are 20 sites.

It was originally thought that trees were a prerequisite for *S. metallica* (Smith & Smith, 1995; Vick, 2004). However, west of Loch Ness, many sites are on upland moorland. Southeast of Glen Affric is an exposed ridge 300 - 400 m a.s.l. above Tomich. *Somatochlora metallica* was first recorded here at Loch Carn Bingally in 1989, where there are no trees. It has been found at ten sites in a string of lochs southwest of this site. Sites have also been discovered from Lochan Dubh near Cannich, northwards and eastwards, where there is a mixture of open moorland and birch woodland.

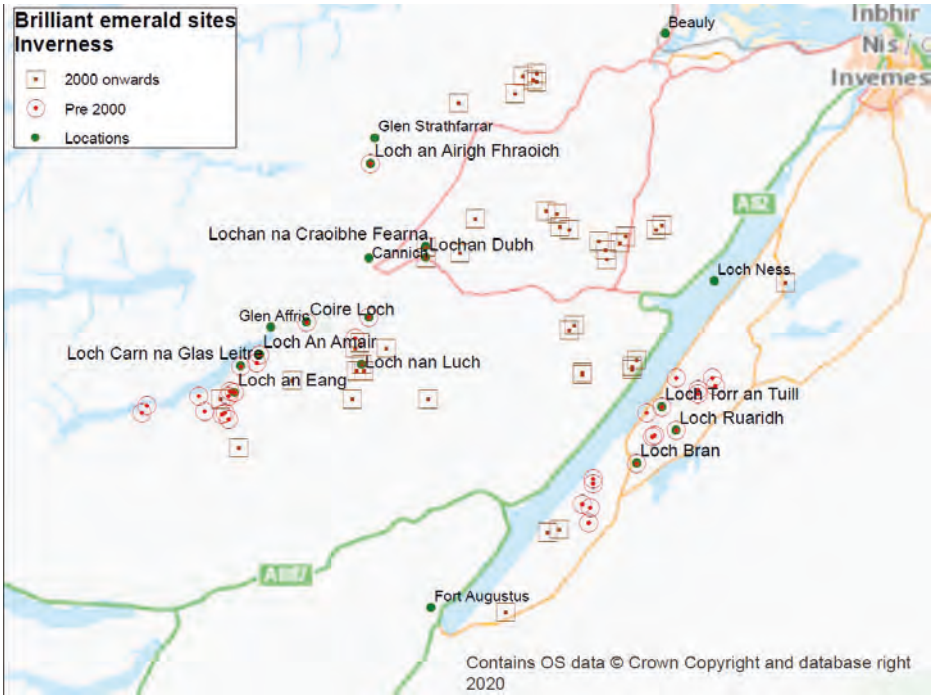

Figure 4. The location of S*omatochlora metallica* sites in Inverness-shire, north-east Scotland. Pre 2000 sites are those first recorded between 1900 and 1999 and they all continue to be viable sites. 2000 onwards sites were first recorded between 2000 and 2021.

Habitat of *Somatochlora metallica* in Scotland

Somatochlora metallica is known from lochs and lochans mainly 150 - 440 m a.s.l. but sometimes even higher, the highest being at Beinn Donachain at 610 m in altitude in Argyll.

The lochs and lochans where *S. metallica* is found, are of various sizes. They are mainly small to medium sized with 90% less than five hectares in area and with differing water depths (Smith & Smith, 1995). Occasionally, *S. metallica* has been found in very small lochans (0.2 hectares) and large lochs (>20 hectares). The surrounding hinterland is also very variable. Some sites are in, or partly bordered by, pine, oak, birch or coniferous woodland, some have scattered trees and others none at all. Sites can also be bordered by mires. Many lochs are open with little vegetation, whilst others have scattered emergent and floating vegetation which is mainly off-shore. The pH of sites seems to be irrelevant (Smith & Smith, 1995).

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This suggests that *S. metallica* is a generalist and can occur anywhere but this is not the case. In Scotland, the following habitat features are present where adult males have been seen or larvae and exuviae found:

1. **Lochans with heather/grass banks** which are from 0.3 m to 1 m high and fairly steep. These are mainly heather, especially in the east, or a mixture of grasses and sedges. Many, but not all, are undercut with an overhang of up to 1.0 m. The water depth below the overhang is usually 0.3 m or more. There are also small inlets at some sites (Plate 1). Exceptionally, some sites have more gently shelving shallow shores.

2. **Open water adjacent to the bank** where males are seen patrolling. Emergent vegetation can be present but is very sparse or off-shore, with a mixture of *Carex spp.* (sedges), *Equitsetum fluviatille* (Horsetail) and *Schoenoplectus lacustris* (Common Club-rush) (Plate 2).

3. **Sphagnum** is not universal but is present at many sites, especially in the west of Scotland. It is often a component of the bank vegetation, forming mats in between the heather (Plate 3). It can form substantial sphagnum lawns such as at Loch Bran (Smith & Smith, 1995). It is a good substrate for ovipositing and provides an easier route for crawling larvae than coarse heather.

4. **Substrate.** The substrate is usually silt, occasionally peaty, sometimes with numerous flat stones. In the Swiss Alps, *S. metallica* prefers areas of open water with steep or undermined banks and a substrate of fine mud similar to the Scottish sites (Wildermuth & Knapp, 1993).

All the original sites In Argyll are hill lochs but *S. metallica* has also recently been recorded at five lochs below 150 m a.s.l. At Loch Ederline, at 38 m a.s.l., just south of Loch Awe, breeding was established in 2020. Males were seen at the small lochan which is attached to the main loch. The area is bordered by Willow Carr (*Salix sp.*) and *Carex paniculata* (Greater Tussock Sedge) swamp over 2m tall. It has extensive emergent vegetation including *Schoenoplectus lacustris* and *Cladium mariscus* (Saw Sedge). Large areas of *Nymphaea alba* (White-Water Lilly) cover the surface, with little open water at the edge (Plate 4). The site is not far away from the Clachandubh burn where a male *S. metallica* was seen patrolling in 2006 (Batty, 2013) and is unlikely to be a newly colonised site. Males have also been seen in the adjacent Lochan Ceann a'Choin. At the other lower altitude sites casual sightings have been made.

Plate 1. Loch na Curaich, 175m a.s.l. (NM863130). showing the grass/heather banks where a male S*. metallica* was seen patrolling.

Male behaviour

From post-2000 records in Scotland usually only small numbers (one to five) of adult *Somatochlora metallica* are typically seen at a lochan at any one time. Fifteen is the most seen at Loch Bran (Benyon & Goddard, 2004). When larger numbers are present, they are usually at the larger lochs, where there are longer areas of bankside for patrolling behaviour. However, nine (including a pair in tandem) have been seen at Loch a'Chrion-doire and eight at the south loch (Smith & Smith, 1995).

In Scotland, adult males have been seen patrolling low over water, close to and following the bank. They fly out of sight and then reappear to patrol the same area again. Marginal emergent vegetation or gently shelving shores are not often used for patrolling. Typical behaviour is illustrated by observations at two sites in Argyll (Lochan na Goirt and Loch Ederline):

Lochan na Goirt. A visit was made to Lochan na Goirt (NM847050) at 161 m a.s.l. on 12 August 2021. The weather was warm (approximately 20°C) with a

Plate 2. Lochan Dubh, Cannich 190m a.s.l. (NH370323), showing open water near the bank. Larvae were found under the banks in this area.

breeze. After heavy rain, it was mainly cloudy at first but improved during the visit, with full sunshine later. The lochan is in a sheltered hollow. Conifers had been clear felled on the south bank with some replanting on the slopes above the loch. To the north is open hill ground with scattered birch and willow. The loch has a stand of *Schoenoplectus lacustris* across the middle, *Nymphaea alba* and *Potamogeton natans* (Broad-leaved Pondweed) and some sedges, but the water surface is open by the bank. On arrival at 14.10 BST there was limited dragonfly activity with *Enallagma cyathigerum* (Common Blue Damselfly), *Lestes sponsa* (Emerald Damselfly) and *Sympetrum danae* (Black Darter) seen. The southern bank has visibly suitable habitat but no *S. metallica* adults or larvae were present.

At 15.00 a male *S. metallica* appeared in the SW bay near the outflow and started to patrol the edge and then disappeared from view behind a willow, flying eastwards along the south bank. A few minutes later it reappeared and then flew north eastwards along the edge of the northwest bank for about 20 m before returning to fly around the willow and then along the bank again.

Plate 3. Dubh Loch Argyll, 260m a.s.l. (NM920089). A hill loch above Loch Awe. The area was once open moorland which has been planted with conifers and is now on the second rotation. The blue arrow shows the sphagnum area. Forty-two *Somatochlora metallica* exuviae were found on heather along the bank, marked with the red arrow. A male S*omatochlora metallica* was seen patrolling the bay.

Between 15.10 and 15.35 a male *S. metallica,* (most likely the same individual) continued to patrol the area, concentrating on the northwest bank. The loch is narrow at this point. The southwest bank is about 0.3 m high over water 0.3 m deep. The northwest bank is lower at 0.1 - 0.2 m with little inlets, and the water is shallower, with a depth of less than 0.1 m and with a stony gravel substrate. The male patrolled close to the bank edge 0.1 m away from, and approximately 0.25 - 0.3 m above, the water for a distance of 30 - 50 m, hugging the bank and following the inlets. It flew around the observer, hovering briefly; otherwise it was constantly on the move, intermittently flying out over the loch and back. There was little hovering, only to change direction, and no interaction with other dragonflies. At one point, where the bank was low, it flew above the bank, about a metre inland, for 10 m parallel to the water's edge, possibly feeding on small insects there. It then perched on sedges on the low bank near the edge for about five seconds. There was open water at the edge of the main patrolling area with very little emergent vegetation. At 15.35 the male flew out of sight.

Plate 4. Loch Ederline 38m a.s.l. (NM867021). A low altitude site with more aquatic vegetation than usual for Scottish sites. The area has extensive Willow Carr and is a small enclosed area of the large loch.

Twenty minutes later a male, possibly the same individual, was briefly seen further east in the mid-area of the north bank flying low, close to the edge, from east to west. It flew in and out of the inlets and below a small birch, continuing without stopping along the bank for another 50 m until out of sight. There were no further sightings before leaving the loch at 16.20.

Loch Ederline Loch Ederline (NM868021), (Plate 4) a lowland site in Willow Carr, was visited on 18 June 2020. At 14.00 two males were seen flying high above the edge of the loch and then flying higher towards the surrounding trees (Plate 5). On two other occasions males were observed on the Clachandubh burn, which is deep at this point and 150 - 200 m from where the burn joins the loch. The first was on 21 June 2021 at around 15.30, where there are overhanging trees on both sides of the burn; the second on 7 July 2021, at 15:00, about 50 m nearer the loch in an area of high banks with tall vegetation (Plate 6). On both occasions a male was patrolling the western bank low over the water, occasionally hovering, with several interactions with one or two

Plate 5. A male *Somatochlora metallica* flying high above Loch Ederline. Photograph by Stephen Carter.

other *S. metallica* males. It then flew rapidly away, towards the loch or up into neighbouring trees. A male then returned to patrol the same stretch of bank again; it is not possible to say if it was the same individual (Carter, S. pers. comm.).

Four males were seen at Loch Ederline on 27 June 2021 patrolling the water's edge. They kept to the same areas, engaging each other when they met at the edge of their territories. They had brief sorties into the carr vegetation, initially flying about 0.3 m above the water and then up to about 2.5 m. This loch has a ring of *Schoenoplectus lacustris* (sparce in places) along the edge of open water (P. Stronnach, pers.comm.).

Similar *S. metallica* behaviour has been seen by other observers (J. Willet, & S. Carter, pers. comm.).

Oviposition

Female *Somatochlora metallica* are more elusive, mainly hiding amongst vegetation at the edge of the bank in little inlets; generally, they are more often seen when ovipositing. From the British Dragonfly Society Scottish Records (British Dragonfly Society, 2021; i record, 2021) ovipositing has been observed on 16 occasions in the 30 years from 1990 to 2020. The earliest record was one seen on 24 June; most were in July and the latest on 11 August.

Plate 6. Clachandubh burn at Loch Ederline where *Somatochlora metallica* males were seen patrolling.

Somatochlora metallica females have an extended vulvar scale uniquely set at 90 degrees to the abdomen and below segment 9. When ovipositing into moss or wet mud, segment 10 and the anal appendages are held at right angles to the body.

Oviposition was observed on 21 July 2021 at Lochan Eisge Mhoil (NN0110) at 330 m a.s.l. in the hills to the east of Loch Awe. This lochan is very open, with little vegetation, and set in a hollow surrounded by steep heather banks. On arrival at the site at 13.00 a female was seen ovipositing into the bank below (Plate 7). She was thrusting her vulvar scale repeatedly, up to 10 times, into bands of sphagnum between the heather, then washing the abdomen by dipping it into water with the tip in the raised position. This was seen at Loch Bran (Richards, 1996). It is not known if any eggs were deposited during this process. The female gradually moved along in the same area of steep bank about 0.20 - 0.30 m above the water. The activity continued for 10 - 15 minutes

Plate 7. Lochan Eisge Mhoil 350m a.s.l.(NN014108). This shows the area where a female *Somatochlora metallica* was seen ovipositing into sphagnum 0.3m above the loch (blue arrow).

before she flew off. This area was open in full sun; the temperature was about 21°C. The lochan is shallow (0.1 m) at the edge, with a substrate of numerous flat stones which could provide a hiding place for larvae. The banks here have leggy heather, which was growing out above the water There was no undercutting of the banks at this point. No males were seen nearby until two hours later when one was patrolling the adjacent loch, which was over a small ridge. The height above the water for ovipositing is interesting as most other Scottish sightings are just above water level. However, Smith & Smith (1995) observed a female ovipositing for two minutes into sphagnum 0.15 m above the water at a site in southern France. Sphagnum moss will keep the eggs moist. Once hatched, the prolarva can wriggle (Corbet & Brooks, 2008) and is thus able to get into the water.

On 30 July 2010 at Loch an Airidh Fhraoich in Glen Strathfarrar a female was seen to 'hammer' or swing her abdomen into the sphagnum at the edge of a small islet in the loch, repeatedly tapping her ovipositor into the moss. No male was present. (Willet, J. pers.comm.).

Other oviposition seen by the author was into the peat on an exposed small peat island, just off-shore. (Batty, 2013). Also, on two occasions, a female was seen ovipositing into moss just above and at the edge of the water in a small hidden inlet. On all occasions there was no sign of the male.

The eggs are spherical with a thin outer membrane and hatch within 4-10 weeks (Grand & Boudot, 2006, Mill, 2012,). In captivity they took 38 days to develop (Corbet *et al*., 1960). Eggs deposited late in the season can over-winter and hatch the following spring (Grand & Boudot, 2006).

Larvae

Somatochlora metallica larvae are very distinctive, with large curved dorsal spines on the abdomen and very long hairy legs (Cham, 2007) (Plate 8). During the day they prefer dark areas (Sternberg & Buchwald, 2000).

In Scotland, larvae are very difficult to find; many days have been spent searching for larvae since 2013. The technique used often involves lying on the bank and sampling underneath it, with a net or colander dependent on the site. Most larvae have been found tucked underneath undercut banks. The undercutting varies but, as noted above, can be up 1.0 m with a water depth of 0.3 - 0.4 m (Batty, 2013). Sphagnum is often a component in areas where larvae are found. At Loch a'Chrion-doire in Argyll, larvae have been found on several occasions at a narrow peninsular with undercut sphagnum banks and inlets (Plate 9). Larvae have now been seen at several sites, though not all sites have deeply undercut banks. Where males have been observed patrolling is usually a good place to sample.

A typical situation is at Loch nan Luch (NH3225) at 350 m a.s.l. on the ridge above Tomich in Glen Affric. It is an open hill loch with limited sedges in the north and south bays. Twenty larvae were found under the west bank, 0.3 - 0.6 m underneath it, in an area with small inlets and just south of the inflow. They were in no or little detritus; that present was decaying heather twigs and thin fibrous material. Similarly, at Lochan Dubh (NH370323) at 190 m a.s.l. above Cannich, larvae have been found under banks in the wooded area to the north, but the best area for *S. metallica* larvae is where there are extensive mires with banks of heather and *Myrica gale*.

Plate 8. *Somatochlora metallica* larva, showing the distinctive curved spines and long legs. Photograph by Steve Cham.

Loch Carn Bingally (NH3328) at 300 m a.s.l, is a small, open, wind swept lochan with heather banks over 1 m high. Having such high banks there are few areas where larvae could easily leave the water (Smith & Smith, 1995). A larva was found at the south end on 21 August 2021 in heather detritus under the bank near a small area of sphagnum which would have provided a means of exit.

Less common places for larvae are under *Nymphea alba* leaves and at the base of sparce sedges at Dubh Loch (NM920089) in Argyll. This and the neighbouring Loch Eireachain do not have undercut banks and it has been difficult to find larvae despite much searching. However, there are areas with a few birch trees and lanky heather growing out over deep water. Here the banks are too steep to search for larvae in the water below without waders. Only once has the author seen a larva in the open and this was in an inlet above brown silt substrate.

Larvae were discovered under rocks in Slovenia (Batty, 2013). However, at Scottish sites there are numerous stones, and silt is often dislodged when moving them so that searching becomes extremely difficult. In England, where ponds are heavily shaded, larvae are found under decaying leaves (Vick, 2004, Mill, 2012). However, *S. metallica* sites in Scotland are usually not like this and

Plate 9. Loch a'Chrion-doire 234m a.s.l. (NN005227), showing the area where larvae of *Somatochlora metallica* were found.

do not have layers of decaying leaves; indeed, larvae have not been found here amongst silt or large quantities of leaves and other detritus, and only occasionally under a few birch or alder leaves. Areas with overhanging trees have been sampled without success.

Loch Ederline, though not heavily shaded, has extensive Willow Carr. The accessible areas of the south bank were searched. Larvae were found under the dead branches of a fallen willow (Plate 10). On three separate occasions they were in the same small area, less than 10 m long, under willow and between *Carex paniculata* tussocks. Even here they were amongst only a little floating detritus and dead leaves. *Brachytron pratense* (Hairy Dragonfly) larvae were also found here. Twice, both species were present in the same sweep of the colander. Exuviae were also found on sedges nearby.

Size distribution

A total of 83 larvae were examined from Scottish sites between 2001 and 2021. The data are from a range of years and from sites at varying altitudes but mainly

Plate 10. Loch Ederline. An area where *Somatochlora metallica* and *Brachytron pratense* larvae were found just off shore from the colander. They were under floating detritus under the branches of the willow.

the higher-level sites. The larvae were measured from the tip of the head to the tip of the paraprocts.

The smallest larvae, 6 - 10 mm long, were seen in early June and early July and then again in mid-September. In June there were larvae of 6 - 8 mm, 10 - 12 mm, 14 - 17 mm and 23 - 24 mm. The largest (23 - 24 mm) larvae were only found in late May and June; these had wing buds fully developed on segment 6 and were at F-0 , i.e. prior to emergence (Fig. 5).

The most larvae seen by the author at a single site was twenty from Loch nan Luch; usually only one to four were found. Here, on 23 September 2020 the smallest larvae were 9 mm; most were between 9 - 14 mm with a peak length of 12 mm. This suggests larvae from the previous year's eggs. The largest larvae (21 mm and 22 mm) were final instars and would over winter to emerge the following spring (final instar larvae are 22-26 mm long (Cham, 2007)). One larva was 16 mm long and larvae in the size range 16 – 17 mm were found at other hill sites at the same time of year.

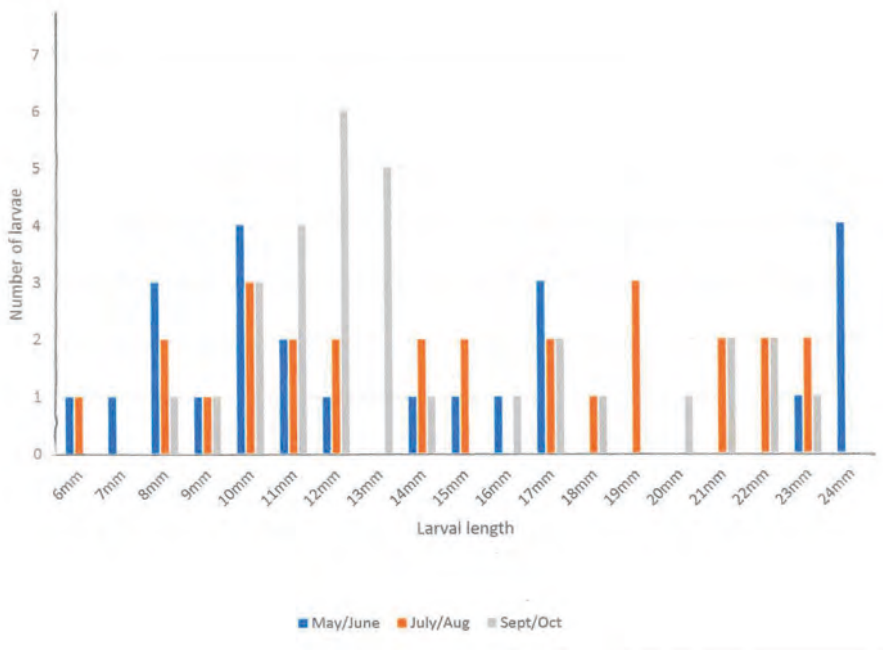

Figure 5. The distribution of the lengths of larvae found in Scotland 2000-2021. The different colour classes show the months when the larvae were found. n=83

Though it is difficult to extrapolate from the limited data the three size peaks are evident throughout the year; when emergence is also taken into account this possibly indicates 3-4 years or more in development in Scotland (Fig. 5).

Emergence and Exuviae

Emergence. Emergence of *Somatochlora metallica* has been observed on eight occasions post-2000. Most sites were in Inverness-shire with only one, Loch a'Chrion-Doire, in Argyll. Emergence occurred mainly throughout June, the earliest observed being on 7 June 2017 at Lochan Dubh and the latest on 23 July 2010 at Loch Bran.

Larvae travel several metres to find a suitable emergence site (Sternberg & Buchwald, 2000), often on heather in Scotland. They can climb up high banks, cross sphagnum lawns and emerge 1.2 m up on fence posts and on trees up to 2 m above the water (Smith & Smith, 1995; Sternberg & Buchwald, 2000; Vick, 2004; Cham 2007; Mill, 2012).

Exuviae. Records for exuvia were noted on 47 occasions in Scotland from 1990

onwards. The earliest they were found was 4 June 2021. The majority (57%) were found in June and 32% in July. There was little difference in numbers between the first and second half of these months. The remaining 11% were found from 2 - 19 August and a single exuvia was found late in the season on 26 September 2005 at Loch a Craoibh Fearna above Cannich. It was in good condition but it is not known how long since emergence had taken place. However, exuviae are easily dislodged by wind and rain and do not usually remain at a site for very long. In Scotland, adults have not been recorded as late as September. Though exuviae are not the best way to give dates of emergence this last finding could possibly suggest a longer emergence period than hitherto recorded.

Most records for any one site are of one or two exuviae. However, on 13 June 2016 at the Dubh Loch in Argyll, 42 exuviae were found on heather along a 50 m stretch of steep heather/sphagnum bank 10 m above the loch. Another 16 exuviae were found at two neighbouring lochs, giving a total of 58 on the same day. This could indicate synchronised emergence.

Relationship with *Cordulia aenea* (Downy Emerald)

Cordulia aenea (Downy Emerald) also breeds in Glen Affric. Of the 21 sites in this area Smith & Smith (1995) found that nine had both species, five had *Somatochlora metallica* alone and seven *C. aenea* alone. The situation is similar now, with only one new *C. aenea* site (at Lochan Dubh above Cannich) which has both species. However, emerald dragonflies are not always easy to distinguish if seen briefly in flight.

Cordulia aenea generally prefers the lower, more sheltered sites, whilst more typically *S. metallica* is found in higher, more open sites (Smith & Smith, 1995). *Cordulia aenea* is the predominant species at Coire Loch, which is in a hollow amongst ancient pines. The higher, more exposed lochs, Loch Carn Bingally, Loch na h Eirdh and Loch Carn na Glas Leitre are more typical for *S. metallica*. Other lower sheltered sites, Loch Amair and Loch na Gabhlacha, have both species breeding. The overlap now covers more sites and is where the two species' habitat preferences are present and are further delineated by the shoreline patrolled (Smith & Smith, 1995), *C. aenea* preferring fringing vegetation and less open water (Table 1).

The hill ground in scattered pine woodland around Loch an Eang and Loch a Chlaidheimh (260 – 360 m a.s.l.) has a number of lochs and very small lochans, 0.2 hectares in area, all of which provide breeding habitat for both species. *Cordulia aenea* flies two to three weeks earlier than *S. metallica* and adults in Scotland are only occasionally seen together. *Somatochlora metallica* exuviae

Table 1. Sites where *Somatochlora metallica* and *Cordulia aenea* have been recorded post 2000. p = adults present b = confirmed breeding records, i.e. exuviae found.

Site name	Grid reference	Height	*Somatochlora metallica*	*Cordulia aenea*
Both species confirmed breeding				
Loch An Amair	NH264261	270m	b	b
Loch Carn na Glas Leitre	NH252254	350m	b	b
Loch an Eang 1st lochan	NH245238	336m	b	b
Lochan Dubh	NH370323	190m	b	b
Loch Bran	NH505192	190m	b	b
Loch Ruaridh	NH530213	190m	b	b
Only *S. metallica* confirmed breeding				
Loch an Eang general	NH248237	310m	b	p
Loch an Eang 2nd lochan	NH244235	350m	b	p
Only *C. aenea* confirmed breeding				
Coire Loch	NH294282	180m	p	b
Loch na Gabhlach	NH262256	290m	p	b
Loch a Chlaidheimh	NH225235	260m	p	b
Loch Pollain Bhuidhe	NH189224	290m	p	b
Pollan Bhuidhe lochan	NH192229	260m	p	b
Loch an Eang 4th lochan	NH239233	360m	p	b
Neither species confirmed breeding				
Loch Torr an Tuill	NH521228	150m	p	p

have been found at sites when *C. aenea* is flying. *C. aenea* larvae have been found in such sites beneath undercut banks where one would expect to find *S. metallica* larvae.

Since 2016, *C. aenea* has been recorded east of Loch Ness at 150 – 210 m a.s.l, in the Loch Bran area. Adults were observed patrolling at Loch Torr an Tuill and, at Loch Bran and Loch Ruairidh, exuviae were also found. This species could

have been overlooked in the past.

In Argyll no sites have yet been found where the two species co-exist, *C. aenea* being restricted to a small number of lower lochs near Oban that have abundant emergent vegetation.

Discussion

There has been an appreciable increase in the number of known sites of *Somatochlora metallica* in Scotland between 2000 and 2012 (Batty, 2013; Cham *et al*., 2014) and this has continued. The number of sites post-2000 has increased from 31 to 109, and the known range from 8 to 25 hectads. This is unlikely to be biological range expansion and is mostly due to increased recording activity targeting this species. There are two populations, one in Argyll and one in Inverness-shire, the latter covering both sides of Loch Ness, linking the Loch Bran and Glen Affric areas.

Many of the sites where *S. metallica* has been recorded are within 5 - 11 km of each other, which could be within the dispersal range for this species. Often where it is found at a lochan it also occurs at the surrounding lochans, even where the habitat looks less suitable. This is suggestive of a metapopulation where local spread occurs between lochans, particularly from core sites with favourable breeding conditions.

The additional sites found add to the importance of open, upland grassland or moorland with now over 45% of known sites in this habitat. Though many of the original sites were in conifer woodland, the presence of trees is not essential (Smith & Smith, 1995; Vick, 2004). However, the occasional willow and dwarf shrub heath can provide shelter in the upland sites. Male *S. metallica* have been seen feeding in forest rides up 3.5 km from the nearest known site. Interestingly the highest known site on Beinn Donachain is above a relic area of native pine woods.

Somatochlora metallica is widespread in Europe, with higher altitude sites preferred the further south in its range. In lowland areas it can also be found in cooler, flowing waters. In Sweden and Belgium, sites are mainly in woodland (M. Billqvist, pers. comm.; G. DeKnijf, pers.comm.); however, in Finland it is spreading into the habitat of *Somtochlora sahlbergi*, which is open and at or above the tree line (M. Billqvist, pers. comm.). The higher altitude and more open Scottish sites are likely to be cooler than lowland sites. Thus, they will not be as affected by high temperatures as are the southern English sites (Cham, 2022). In Western Scotland the main problem has been sufficient warm

days with weather conditions suitable for recording flying adults. Adults are generally seen throughout the day when conditions allow. In the past two years, temperatures have been higher, with 26°C recorded in the valleys but several degrees cooler at the hill lochs. From limited experience the author has not seen adult *S. metallica* activity when temperatures reach 24 - 25°C at a site. Adult flight at the Inverness-shire sites with hotter summers is more likely to be affected by higher temperatures.

It has been suggested that *S.metallica* prefers areas with more oxygen (Sternberg & Schmidt, 2000) and hill lochs are exposed to wind and waves, increasing their aeration. Males patrol areas near inflowing or outflowing burns but larvae are found in a range of places, including calm sheltered water under willows. This is less likely to be a factor than temperature, as most sites are in cooler upland areas.

Most of the behaviour observed is from sites with a low density of males and few other large dragonflies; thus there is likely to be less intra- and inter-species aggression. Hovering has been observed when other males were present but not as frequently as described at English sites (Cham, 2022). The controlled purposeful flight is similar to that described by Ward-Smith *et al*. (2000).

Females are generally thought to be secretive, but in Scotland they do oviposit in the open when there are no males patrolling nearby. The presence of shade does not appear to be a factor unless temperatures are high (28°C) (Richards,1996). Females have been observed ovipositing at various times during the day.

It was originally thought *S. metallica* was confined to higher level sites in Scotland, i.e. a different habitat from the sites in southern England. The new lowland site at Loch Ederline at 38 m a.s.l. has extensive emergent and floating vegetation and willow carr. It is possibly more like the shaded English lakes (Vick, 2004; Mill, 2012; Cham *et al*., 2014). This loch and other lowland lochs are part of the Loch Awe network. However, *S. metallica* does not widely use this habitat as it has not been found at similar well visited lochs further south in Knapdale.

Somatochlora metallica has been regarded as a ‘Spring’ species (Sternberg & Buchanwald, 2000; Corbet & Brooks, 2008), where larvae suspend development in the final instars during their final winter for synchronised emergence in the spring. Final instar larvae of 22 – 24 mm were found in September/October and in June before emergence, thus supporting this. Emergence in England starts in June, peaking in mid-June (Vick, 2004). Emergence dates vary with weather conditions. In Scotland, sites vary in size and exposure. Some records are from

Argyll in the west which has a milder, wetter climate than others from Inverness-shire where the winters are colder drier and the summers sunnier. The main emergence is likely to be earlier in the west than in the east, and earlier in the more sheltered woodland sites than in hill lochs.

From the limited data for Scotland, which spans a number of years, the main emergence seems to be from early June through to 23 July, with 4 June 2021 being the earliest date exuviae were found. Though the majority of exuviae were found through June and July, some were in August and one in September. Although the survival time for exuviae is unknown this data could indicate a longer emergence period. Thus perhaps *S. metallica* does not behave strictly as a spring species in Scotland. Emergence seems to be over an extended period in Germany (Sternberg & Buchanwald, 2000). Counter to this argument, however, 58 exuvia were found in Argyll on 13 June 2013, which could imply a more concentrated emergence. Records for *S. metallica* in England suggest there may be two peaks of emergence (S. Cham, pers. comm.); the first from well-advanced larvae that over-wintered in the final instar, the second from earlier instars which developed further in the spring/early summer.

The time given in the literature for larval development is 2 - 3 years (Smith & Smith, 1995; Mill, 2012). However, more recent larval data from Scotland indicates development could be longer here, i.e. 3 - 4 years. The species is widespread across Europe from montane parts of the south to the Alps, so there is likely to be a large variation in development conditions and growth rates. In Scotland, larvae are in the shade under the banks of cool hill lochs; thus the growing season for larvae is likely to be relatively short. This is especially so in Inverness-shire, which has cold winters and where night-time frosts extend into spring and autumn. Thus, water temperatures are likely to be cooler, taking longer to heat up in the spring and cooling earlier, than at the lower English sites. There is also likely to be less food available in the upland lochs.

Future work

Somatochlora. metallica is an under-recorded species. There are few recorders in Scotland and a high number of unexplored lochs and lochans with potentially suitable habitat. Many are remote sites and difficult to access, and favourable weather can be limited during the flight time. More recording is required in an effort to locate additional sites in new areas, with the possibility that sites may be found that link the currently well separated populations in Inverness-shire and Argyll.

More detailed research is needed to investigate the development duration and habitat requirements of this species and factors affecting the two disjunct

populations of *S. metallica* in England and Scotland.

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Observations of behaviour and activity patterns of *Somatochlora metallica* (Vander Linden) (Brilliant Emerald) at sites in England.

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Summary

Observations of *Somatochlora metallica* (Vander Linden) (Brilliant Emerald) at sites in England show behaviour and activity patterns that differ from those described in UK field guides and other publications. During periods of favourable weather, males start patrolling territories earlier in the day than previously reported. Digital photography provides a means to identify the species in flight and differentiate between different individual males. The durations of patrolling and hovering flight and the causes of changes in male territorial behaviour are discussed.

Introduction

Somatochlora metallica (Vander Linden) (Brilliant Emerald) is a rare dragonfly in Britain, confined to a disjunct cluster of sites in southern England and Scotland (Cham *et al*., 2014; Batty, 2022). The elusive nature of this dragonfly is reflected in the low number of records in the BDS recording scheme, representing only 0.002% of the total of >1.6M records. Even in its strongholds in England it is considered to be scarce and rarely seen (Beldon *et al.,* 2004; Crick, 2016; Ward-Smith *et al*., 2000; Ward-Smith, 2013). Due to its scarcity *S. metallica* attracts the attention of naturalists and photographers seeking it for the first time. From discussions with novice observers there appears to be confusion relating to the observations made in the field, arising from the somewhat differing and conflicting descriptions of behaviour stated in field guides and other literature. Mill (2012) has also drawn attention to some of the conflicting descriptions of behaviour. In many cases first encounters with *S. metallica* and the closely related *Cordulia aenea* (Downy Emerald) are of males in flight while they patrol pool margins, yet many of the field guides only show illustrations of perched individuals. Both species will occasionally settle and not always within close view of the observer. One very often has to rely on identification in flight. This study reports observations and new insights into the behaviour and activity

of *S. metallica* conducted between 2005 and 2021. It highlights some of the anomalies in previous descriptions of its natural history in Britain.

Methods

Site

Observations of *Somatochlora metallica* and *Cordulia aenea* made between 2005-2021 at sites across southern England were supplemented by digital still photography to record flight behaviour. Locations included still water pools at Bramshill Plantation (SU7562), Chobham Common (SU9963), Decoy Heath (SU6163), Esher/Fairmile Common (TQ1262), Horsted Keynes (TQ3929), Swinley Forest (SU9067), Thursley Common NNR (SU9041), Wasing SSSI (SU5863) and, most notably, Warren Heath (SU7758) (Fig. 1).

The middle reservoir at Warren Heath (Plate 1) proved to be a good site to make close and repeated observations of male flight behaviour and activity patterns and became the focus of further study. Located in an area of extensive forestry that forms continuous woodland with Heath Warren and Bramshill Plantation to the immediate north, it is one of three reservoirs linked by a small stream. Early maps show it to have been created in the early 1920's before the surrounding areas were reclaimed from mineral extraction (Crick, 2016). The middle reservoir is triangular in shape and fed by a stream at the east end and with a dam at the west end. The north margin of the pool is lined with trees and a hinterland of extensive conifer plantation. The south margin is mainly open, with small bushes and Birch trees at intervals along the bank (Plate 1). The southern bankside and the area adjacent to the pool have previously been cleared of trees, rhododendrons and a conifer plantation. Apart from a small area of *Typha* sp. (Reedmace) at the stream end there is no emergent or floating plant growth in or around the pool. The water is relatively clear but stained brown and is mildly acidic (pH 6.5, K. Crick *pers.com.).* The bottom substrate comprises silt with an overlay of pine needles, decomposed and fragmented broad leaves and other coarser organic debris of twigs and small branches.

During 2008/9 the dam of the middle reservoir at Warren Heath developed a serious breach, resulting in a substantial drop of water level which lasted several years. It was repaired in January 2013 and former water levels were subsequently restored. The breach occurred prior to the clearance of the conifer plantation and bankside trees on the southern margin of the pool in 2013/14. These events provided the opportunity to assess the impact of major habitat alteration on the *S. metallica* population and activity. An increased frequency of visits were made on days with a warm, sunny weather forecast in June and July

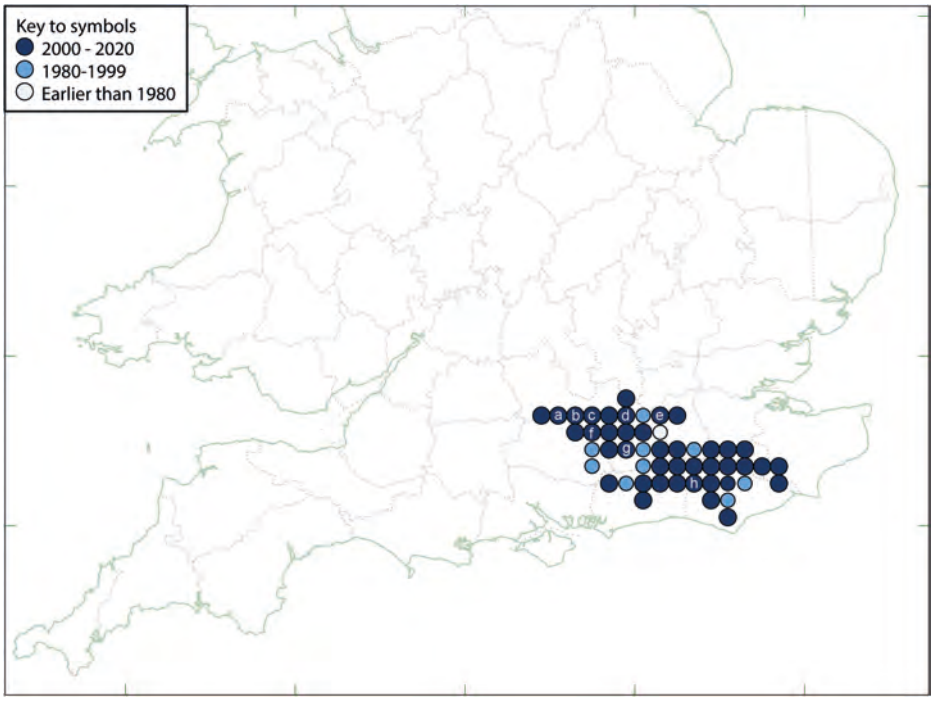

Figure 1. Spatial distribution of *Somatochlora metallica* in England showing the hectads including the study sites. a) Wasing SSSI incorporating Paices Wood, b) Decoy Heath, c) Bramshill Plantation, d) Swinley Forest and Chobham Common, e) Esher Common, f) Warren Heath, g) Thursley NNR Moat Pond, h) Horsted Keynes Lakes.

and into August during 2018-2021. Visits typically commenced at 06.00 BST, or soon after, to record the first arrival of dragonflies at Warren Heath middle reservoir water. All times are BST.

Equipment

Most of the water surface at this pool can be observed from anywhere along its margins, enabling odonate activity to be quickly detected. To support direct observation the use of cameras with fast autofocusing systems (Canon 7D, R5 and M6 mk2 with 100-400mm L lens), set to shoot at 8-12 frames per second using mechanical shutter mode (see addendum), enabled the recording of flight sequences of patrolling males. Date and time recorded in the EXIF metadata with each image enabled later analysis of times of activity, providing an indication of differences, namely intervals between males patrolling certain areas and the duration of bouts of hovering when searching for females. Some males could clearly be identified in flight in the digital images by unique markings,

Plate 1. The main study site at Middle Reservoir, Warren Heath looking south-west (10 August 2021), showing the south bankside (top left) utilised by patrolling males.

abnormalities or tears on their wings, providing supplementary information on how long individual males were present in one area. A Proster handheld anemometer was used during visits to record air temperature and wind speed on the bankside.

Observations of females were infrequent and unpredictable. Tandem, copulation and oviposition were only seen on a few occasions, during which attempts were made to closely observe and photograph this behaviour. Larval sampling was undertaken to confirm that the pool was a breeding site and suitable for larval development. The sampling for larvae was carried out after the adult flight period had ended. On 29 August 2021 a pond net was used to search for larvae in two areas of bank where males had been observed hovering repeatedly.

Results

Emergence

Emergence of *Somatochlora metallica* at the sites in England typically occurred in the mornings throughout June and were observed from the earliest date

of 4 June (at Thursley Common NNR in 2006). Exact dates and times of the start of emergence varied from year to year depending on prevailing weather conditions. Notably, *S. metallica* emerged several weeks after *Cordulia aenea*, and for much of July both species could be seen flying together. Over the period 2005-2021 males of *S. metallica* were recorded flying in early morning, with the highest counts of males before 08.00. This early morning activity was recorded (earliest time in brackets) at Warren Heath (06.48), Thursley Moat Pond (06.55) and Black Pond, Esher Common (07.15). Flying males were also observed, mainly as singletons, at most times of the day, flying both in shade and open conditions.

At Warren Heath on 13 June 2021 a number of *S. metallica* exuviae and a newly emerged adult were recorded on bankside vegetation within 1.0m from the water's edge. This was a good indication that emergence had commenced. No mature males were seen patrolling at water during June. Throughout June, mature males of *C. aenea* were abundant and at their peak and usually the first dragonflies to arrive at the pool, with the earliest arrival time recorded at 06.05 while some mist was still over the water. From mid-July onwards *C. aenea* numbers were declining, nearing the end of the flight period, and *S. metallica* was reaching its peak.

Male Behaviour

Five early morning visits to Warren Heath were made during July 2021 on days with a favourable weather forecast. On 22 July 2021, during a period of high pressure, afternoon temperatures reached a high of 30°C. Observations at the middle reservoir on this day were representative of other similar early morning visits. At 06.00, the sun had already risen but was still behind the trees and not yet shining directly on the water. There was a light wind with remnants of mist still gently swirling over the water and the bankside temperature was 17°C. Midges (species unknown) were swarming over the water surface from 06.45, being noticeably highlighted by the low early morning sun. The first dragonfly to arrive was a *Somatochlora metallica* male at 06.50, with the south pool margin now in sunlight and the bankside temperature was 18.5°C. Other *S. metallica* males arrived soon after and, over the following 45 minutes, between six and eight were present at any one time. By this time most of the pool was in sunlight.

On arrival, some of the males would touch the water's surface with the tip of their abdomen, presumably as a means to confirm that it was water (Corbet, 1999). During this period males would patrol the margins, occasionally breaking off and flying out over open water to interact with other males. The preferred banks were unshaded and males were flying in full sunlight. Up to three males would sometimes interact before going their own way and continue patrolling

Plate 2. Male of *Somatochlora metallica* flying close to the water's surface investigating, but making no attempt to contact, a Pond Skater.

the margins. Patrolling males would hover frequently at intervals along the bank, varying in height from 0.15 - 0.6 m above the water and from 0.1 - 1.0 m from the edge. They would investigate any movement and on several occasions were attracted to the movement of Pond Skaters (*Gerris* sp.) on the water surface (Plate 2), although there was no attempt to make contact. Males were sometimes observed hovering over ground, facing the water's edge. Males would also occasionally break from patrolling and fly up to catch and consume midges in flight. During early morning visits in June and July 2018-2021 there were swarms of small midges over the water of the middle reservoir up to a height of approximately 2 m (Plate 3). Depending on air temperature and lingering mist these were present from 06.30 – 08.30; dispersing or less abundant thereafter.

From 08.00 male behaviour appeared to change and activity started to decline, with fewer males interacting and less frequent patrols and hovering. Although the length of patrolled margin was not measured for any male, it was estimated and was suggestive that, as the number of male sightings decreased, the patrol length became longer. This was supported by the increasingly longer intervals between males returning to where the author was positioned with the camera. On several occasions males were seen to leave the water and fly up into the

Plate 3. A midge swarm over water (07 July 2018 @ 06.52 BST). Inset shows a male flying through the swarm at 06.53.

nearby pine trees on the northern bank and lost from sight. Males of *Cordulia aenea* were also present, with occasional sightings of females of this species observed ovipositing in the centre of the pool. They were quickly intercepted by males and carried off and up into tree cover. By 10.30 the bankside temperature was 22°C and most *S. metallica* activity had ceased in some areas or was infrequent. An occasional male would be observed patrolling along the bank, now partially in shade. The inter-species aggression, notably between males of *C. aenea*, *Libellula quadrimaculata* (Four-spotted Chaser) and *Orthetrum cancellatum* (Black-tailed Skimmer) had markedly increased by this time. The remaining *S. metallica* males would come under repeated aggression during patrol flights and would often leave the water as a result. Observations were concluded at 12.15 after no further males were recorded. The bankside temperature at this time was 27°C.

On 22 July a male with a clearly damaged right forewing with two noticeable tears was identifiable over a period of at least 15 minutes. This male was first photographed in flight at 06.55 and then observed to patrol a stretch of bankside. It was again recorded in the same spot at 06.57, 07.00, 07.03, 07.05, 07.06 and

Plate 4. An extract from a time sequence of a male *Somatochlora metallica* with distinguishing tears in its right forewing (arrows), taken at the same place on the south bank (22 July 2021 @ 06.57, 07.05, 07.06, 07.10 BST).

07.10 (Plate 4). These observations suggested that this male was patrolling a relatively short length of bankside and repeatedly returning to, and hovering at, the same spot over this period. At 07.25 another male was photographed in the same spot, this time lacking the tear, yet with several darkened cells in distinctive places on the wings. This male hovered, patrolled and was then recorded again at 07.30, 07.38 and 07.44. At 07.45 a third male was photographed from the same spot of bankside which lacked any of the afore mentioned markers. After an interlude in activity the male with the dark wing cells seen at 07.25 was again photographed at 07.55 at the same place. After this time activity levels dropped and were very infrequent in this one area of bankside.

At 07.57 on 15 July an observation of a male hovering is of particular note. An unsuccessful attempt by this male to intercept a female was followed by a period of extended hovering 1m above the area of ground close to the bank where the contact was lost. This male hovered 1.5 m from the water's edge in the same place for at least 35 seconds (Plate 4). It hovered in one direction and then turned though an angle of approximately 90 degrees, and then again and again in another direction. This male was identifiable by a slight deformation on the upper left side of S2 and was later photographed while patrolling the pool margin nearby. While hovering it appeared to be continually scanning the area for the lost female. This behaviour is similar to hovering flight observed in some

Plate 5. A male *Somatochlora metallica* hovering over ground 1.5 m away from water after failing to connect with a female. Note the distinguishing damage to S2 (arrowed). The bracken stem in the background indicates that the same position was maintained during this bout of hovering.

species of Hawker (*Aeshna affinis* (Southern Migrant Hawker), *Aeshna cyanea* (Southern Hawker) and *Aeshna mixta* (Migrant Hawker)) while searching for females (*pers.obs.*).

Female Behaviour

Females of *Somatochlora metallica* were only occasionally observed at Warren Heath by the author during the period 2018-21. They had been observed in previous years ovipositing along the south margin where larvae had also been found. A pair in cop was observed at 07.45 on 9 July 2021 within 1.5m of the water in bankside vegetation, but flew off before they could be photographed. During the five visits to Warren Heath in July 2021 on no occasion was a female seen ovipositing.

On 1 July 2021 at 09.50 at Black Pond, Esher Common a female flew into a shaded section of bankside and started to oviposit within 1m of the author, allowing close observation. She hovered over an area of wet mud and grass at the water's edge, repeatedly stabbing her vulvar scale into the substrate. While doing this, segment 10 and the anal appendages were held at 90° to the other abdominal segments. Oviposition lasted for seven minutes and was interspersed with brief dips of the tip of the abdomen into clear water, presumably to remove any dirt and detritus before recommencing. After this she flew up into the trees.

Larvae

On 29 August 2021 two areas were sampled for larvae along the south margin of the middle reservoir at Warren Heath. Seven early instar larvae of *Somatochlora metallica* were located in bottom substrate close to the bank. These larvae were probably from the cohort of eggs deposited in 2020 and therefore likely to develop and emerge in 2022. Early instar larvae of *C. aenea* (x1) and *L. quadrimaculata* (x4) of similar size were also found within 0.6m of the bank in bottom substrate.

The drop in water level at Warren Heath appeared to have no effect on larval presence. During the period of the dam breach at the middle reservoir at Warren Heath there was a substantial drop of water level by up to 2 m from normal levels (Plate 6A, 6B). This exposed substantial areas of the bottom substrate comprising silt, twigs and branches and other organic debris in areas typically utilised by *S. metallica* larvae. Adults were still recorded each year throughout this time (K. Crick *pers.com*.). Indeed, male *S. metallica* were evident and observed patrolling the dam end where the water depth was still around 1m. Larvae were found in the water that remained. Exuviae were also recorded.

Discussion

Somatochlora metallica is an infrequently observed dragonfly at many of its sites in England and Scotland and so observations of behaviour and activity patterns are limited. This paper goes some way to addressing this omission. Some of the observations of male *S. metallica* flight traits, whereby it adopts different flight styles involving patrolling and hovering at varying heights and distances from the bank, have previously been reported (Ward-Smith *et al*., 2000). The observations of male behaviour in this study are predominantly from a few sites in southern England on days with favourable warm weather, and therefore may only be representative of these specific conditions. However, they do indicate behavioural and activity traits that contrast with those previously published (e.g. Brooks, 2004, Riley, 2020, Smallshire & Swash, 2018).

Early morning odonate activity is rarely noted and published. It has been considered that, in good weather, the best time to observe adults is between about 09.00 and 20.00 (Vick in Brooks 2004; British Dragonfly Society, 2021). In this study the greatest activity levels of *S. metallica* males, made during favourable weather conditions, were recorded before 08.00. They declined thereafter to a point where males were only occasionally observed patrolling and often in more shaded areas. The previously published times are therefore more likely to represent the times when dragonfly observers are active, rather than the dragonfly itself.

The flight and hovering behaviour of *S. metallica* males have been described in recent field guides in different and contrasting ways; "territorial males patrol water margins often under trees keeping slightly higher and farther from the shore than Downy Emeralds and not pausing to hover as frequently" (Smallshire & Swash, 2018), "Brilliant Emerald flies faster and pauses less frequently to investigate shady nooks" (Brooks, 2004) and "males patrol low over the margins of their breeding waters in determined style, rarely back-tracking or hovering" (Riley, 2020). Observations made during this study differ from these descriptions of *S. metallica* and allow distinction from the behaviour of *Cordulia aenea*.

Somatochlora metallica males hovered frequently and often for longer than *Cordulia aenea*, as well as flying over open water away from shade. Males were also frequently observed hovering close to the bank in full sunlight and, due to the longer bouts of hovering, had the benefit of being much easier to photograph in flight than *C. aenea*. In addition, when the two species were present together, the males of *C. aenea* would appear to have a more 'frantic' behaviour, flying rapidly to intercept and clash with other males. In contrast, males of *S. metallica* would clash, 'see off' the intruding male and then recommence patrol flights along a length of the margins, regularly returning to and hovering at spots that

Plate 6. Middle reservoir at Warren Heath (similar view to Plate 1 but before tree clearance). A series showing the drop of water level as a result of the dam breach and the restoration and recovery of the water level. Patrolling males were observed each year during this period. (A) 26 August 2007 showing original water levels before the dam breach, (B) 19 August 2009 showing notably low water levels after the dam breach. Compare this with Plate 1 taken from same viewpoint, (C) 29 March 2012 showing improving water level after the dam breach and dam repair, (D) 27 May 2013 showing restored water level and repaired dam. (A-C) looking west, with the site surrounded on all sides by an extensive conifer plantation, (D) looking east.

might attract females.

Ward-Smith *et al*. (2000) reported *S. metallica* to have a generally slower and more purposeful flight than *C. aenea* and this is supported by the observations in this study. Males were seen leaving the water, sometimes flying up into the trees. The identification from in-flight photographs of individual males returning to the water indicates that they are leaving the water at intervals, possibly to feed nearby, and then returning to patrol again. Patrol length appears to vary depending on the number of males present. Whilst in-flight photography has limitations and is not a substitute for detailed study using unique marking (capture, mark, recapture) these observations are suggestive of a similar form of 'time-sharing' behaviour as observed in *C. aenea* (Brooks *et al*., 1997; Cham,

2004).

It has also been stated that *S. metallica* flies 0.8 - 1.3m above water keeping 1 - 2 m from the edge and flying as much as possible under overhanging trees. The observations in this study occasionally show *S. metallica* flying closer to the bank and the water surface than previously reported (Brooks, 2004). Similarly, *C. aenea* flies just as fast and at similar height and distance from the bank as *S. metallica*. In both species, the first arrivals in the early morning spend time patrolling the margins with frequent interactions with newly arriving conspecific and heterospecific males. Early morning is the time of day when males have to establish a territory to patrol and defend against rival males. They are constantly adjusting their behaviour and patrol length as more males arrive, with rapid flights by males of both species made across open water in full sunlight to engage rivals. Corbet (1999) proposed that interspecific interaction may considerably reduce the time males can spend at the rendezvous (breeding) site, with interactions of mature adults of syntopic species usually reduced by differences in the pattern of daily activity. It should also be noted that *C. aenea* typically occurs in higher numbers than *S. metallica* and therefore males of the former species encounter a higher frequency of repeated intra- and inter-specific clashes with other males. This accounts for the observed 'frantic' behaviour of *C. aenea*. *Somatochlora metallica* generally occurs in low numbers and therefore will patrol over longer stretches of pool margin except in early morning when patrol length appears to be shorter due to more conspecific males being present. Ward-Smith *et al.* (2000) conjectured that the slow, controlled flight adopted by *S. metallica* is equivalent to the minimum-power speed of aircraft flight and thus a well-adapted energy conservation strategy.

There have been inconsistent statements about the flight attitude of males of *S. metallica*. They have been described as having the abdomen held level with drooping anal appendages (Follett, 1996), whereas *C. aenea* flies with its abdomen held slightly curved upwards at an angle (Miller, 1995). Beynon & Goddard (2004) reported that males of *S. metallica* fly with a characteristic head-down attitude at a somewhat steeper angle than in *C. aenea*. These descriptions likely reflect local conditions on the day of observation and are too generalised to be helpful for identification. Many dragonflies are adjusting their abdomen, particularly during hovering flight, and using this as a characteristic to distinguish the two species is likely to prove unreliable. In the present study the males of *S. metallica* observed and photographed showed a range of attitudes during patrolling flight and while hovering. In patrolling flight, the abdomen was more frequently held level whereas in hovering flight the abdomen was constantly adjusted in response to localised wind conditions; angled upwards or straight in order to maintain the head level, enabling it to scan the surroundings (Plates 4, 5).

It has also been reported that the males of *S. metallica* are less reluctant to enter shaded overhangs compared to *C. aenea* (Corbet & Brooks, 2008), with males secretly patrolling over water close to the edge, often flying under overhanging trees (Dijkstra *et al*., 2020). It is also recorded flying in full sunshine at mountain lakes (Dijkstra *et al*., 2020). Observations in the present study show that, during the early morning peak of activity, patrolling males are very evident in open conditions, in full sun away from shading trees. This fits well with observations in Scotland (P. Batty, *pers.com*.) and mountain lakes in continental Europe (Boudot & Kalkman, 2015; Dijkstra *et. al.,* 2020). As the day progresses and the air temperature rises, sightings of *S. metallica* in the open become less frequent and then males do indeed appear to favour more shaded areas. There are two possible explanations for this:

1. Aggression from males of syntopic species has been cited as a possible reason for *S. metallica* males seeking out more shaded margins. This is postulated as a possible strategy of *S. metallica* to minimise inter-species interactions (Ward-Smith *et al.,* 2000). At Warren Heath, *S. metallica* and *C. aenea* were the first species to arrive at water when they first established territories. As the day progressed, they were joined by *L. quadrimaculata* and *O. cancellatum* both of which are more aggressive, resulting in an increased frequency of interspecies clashes. Observations of patrolling *S. metallica* males prior to the removal of the conifer plantation at Warren Heath in 2013 showed them patrolling throughout the day in shade along the southern margin. At that time the shadier conditions, from conifer trees on the south side of the pool, were less attractive to other species than they are now and there were much fewer interspecific clashes.

2. As a species with a predominantly northern/alpine distribution (Corbet & Brooks, 2008) males are changing their behaviour in response to increasing air temperature and then flying in the lower temperatures provided by shade. These are also the areas where the females are likely to arrive to oviposit uninterrupted. In southern Europe *S. metallica* is increasingly confined to montane areas (Boudot & Kalkman, 2015) where temperatures will be cooler. At higher latitudes in Scotland, where temperatures are also cooler, *S. metallica* is found in more open habitat (Smith & Smith, 1995; Batty, 2013) than the wooded pools in southern England. Males are observed flying in the cooler daytime temperatures which are similar to those of early morning in England (P. Batty, *pers. com*.). This suggests that adult *S. metallica* may require a lower optimal temperature range for extended activity compared to other syntopic species (Cham, 2022).

The conclusion that *S. metallica* rarely takes prey at the water (Vick in Brooks, 2004) was not confirmed during this study. Male *S. metallica* were observed taking midges on a number of occasions while patrolling and during flights across the pool, confirming that they are indeed feeding over water (Plate 3 inset). Feeding over water has also been observed at a pond at Chobham Common on a day when flying insect prey was plentiful over water (9 July 1997 *pers.obs*.).

The act of copulation and oviposition by *S. metallica* females are rarely witnessed events, especially at sites in England (Ward-Smith, 2013). Indeed Ward-Smith *et al*. (2000) questioned whether mating activity occurs mainly early in the day, or in the evening, due to the lack of observations of copulation behaviour during the day. It was not possible for the author to remain on site to record activity at the end of the day due to early start times and long days. The need for further study of *S. metallica* females at this time remains. However, females have been reported ovipositing in the afternoon (around 14.00) at Warren Heath, at the margin of the middle reservoir where the water is shallow and submerged branches are near the surface (K. Crick, *pers.com*.). Here the females were reported to 'parachute' out of the tree cover from high up to oviposit and then return to the tree tops.

It had been suggested that there may be differences in oviposition behaviour between the Scottish and English populations (Fox, 1989) but it was later conceded that this was based on limited observations (Fox, 1991). There appear to be more reported observations and descriptions from Scotland (Smith & Smith 1995; Batty, 2013) compared to the larger and more widespread population in southern England. Females of *S. metallica* have a very prominent vulvar scale compared to other exophytic species, which is used to deposit eggs directly into the chosen substrate (photo. by C. Brochard in Mill, 2012) rather than scattering into the water. Corbet (1983) suggested that the extended vulvar scale may be capable of distance measurement to deposit the eggs more precisely in the substrate during the stabbing actions. There has also been some discussion about illustrations indicating the females raising the last segment and anal appendages through 90º during ovipositing (Powell, 1999). This was challenged by Beynon & Goddard (2004) who suggested that it would be counterproductive for a female to do this when the abdomen is held horizontal.

Observations of female ovipositing, such as that at Black Pond, Esher and elsewhere (*pers.obs*.; Tiensuu, 1945; Pratz, 1989; Smith & Smith, 1995) confirmed that Powell (1999) was indeed correct in his illustration. This is also shown well in published photographs (D. Sadler, 2021) and videos (Berryman, 2014; Adobe, 2021; Shutterstock, 2021). During oviposition, which is by repeated thrusts of the vulvar scale into the substrate, terminal segment 10 and the anal

appendages are held at right angle upwards. Oviposition is interspersed with intermittent dips into clear water to clean debris from the ovipositor (*pers.obs*.; Pratz, 1989; Richards, 1996; Berryman, 2014). Similar cleaning behaviour by exophytic species has also been observed in females of *Orthetrum coerulescens* (Keeled Skimmer) (*pers.obs*.) after they have been ovipositing over plant debris in chalky mud. It is, therefore, reasonable to conjecture that there are no regional differences of oviposition behaviour of *S. metallica* in Britain or elsewhere, even though the utilised substrates may be different depending on local conditions.

Oviposition is the definitive action for a dragonfly when selecting a breeding site. It ensures eggs are deposited in places that give the larvae the best chances of development to adult. Just as adults of *S. metallica* encounter aggression from other syntopic species, so the competition for resources continues during the larval stages. Female *S. metallica* oviposit very close to the bank, often in the drawdown zone where there is wet mud and dead plant material. The enlarged vulvar scale facilitates the placement of eggs in the optimal place compared to females of other syntopic species such as *C. aenea*, *L. quadrimaculata* and *O. cancellatum* that oviposit more freely over open water. Early instar larvae of *S. metallica* have been found very close to the bank edge at the middle reservoir at Warren Heath, which suggests that this may provide a niche for larval development away from other species.

Dragonflies face many threats to their freshwater breeding habitat from human activities. For a rare species such as *S. metallica* with a limited spatial distribution this can be especially concerning. Removal of bankside trees and dredging have been cited as having an adverse effect on *S. metallica* (Vick in Brooks 2004; British Dragonfly Society, 2021). The clearance and removal of the conifer plantation and bankside trees (Plate 6A) from the south margin of the middle reservoir at Warren Heath has had little or no impact on the numbers of *S. metallica* present. The same reservoir also had a major dam breach in 2009 after falling into disrepair, resulting in a notable drop in water levels of 1.5 - 2 m and exposure of all the margins (Plate 6B). The dam was not fully restored until 2013 (Plate 6C,D), yet the population of *S. metallica* appears unaffected, with sightings of patrolling males reported throughout this period.

Conclusions

Somatochlora metallica is an elusive species and sightings can be irregular and unpredictable at most sites, presenting difficulties for study of activity patterns. The early morning observations from Warren Heath and other sites have occurred repeatedly since 2005 and are therefore considered not to be one-off behaviour or specific to any one site. The author considers the often-conflicting

statements in the literature relating to flight behaviour and activity highlight the limited observations of this species in England at times when it is active. A limitation of the past and present recording forms for the BDS recording scheme is that they do not require the time of each record to be noted. It is hoped that this might change, giving the option to record the time, temperature and wind strength for each observation, which will add additional value to each record and thus enable factors affecting peak activity to be assessed in the future.

The visual observations, supported by modern camera techniques, presented in this paper assist in distinguishing between *S. metallica* and *Cordulia aenea* whilst in flight, precluding the necessity for the two species to be netted in order to confirm their identification. Modern cameras, including mobile phones, are capable of capturing fast moving subjects that produce photographs of sufficient quality to aid identification in flight. It is hoped that the observations reported here will encourage others to observe and record natural behaviour, including the time of its occurrence, and so contribute to a better understanding about this and other dragonfly species' behaviour and ecology.

Addendum

A cautionary note should be added relating to the use of digital cameras, notably mirrorless models of all brands which have electronic shutters. Due to an inherent limitation in the technology, images captured using the electronic shutter mode can show artefacts in fast moving objects due to the way the rolling shutter scans and records the image. With dragonflies in flight this manifests itself as distortion of the wings, which gives a very false impression of natural movement and behaviour (Plate 7). Until the promised new improved global shutter designs are available the mechanical shutter is recommended as the best option for in-flight photography of dragonflies with these cameras.

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Plate 7. The rolling shutter effect of the camera's electronic shutter mode can result in distortion of fast-moving wings during flight.

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Habitat suitability for *Coenagrion hastulatum* (Charpentier) (Northern Damselfly) in North-east Scotland

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Summary

Coenagrion hastulatum (Northern Damselfly) is a widespread and abundant species in northern Eurasia but in Great Britain it is classed as Endangered with a distribution restricted to north-east Scotland. Even within north-east Scotland, populations remain small and scattered. There has been no long-term monitoring for *C. hastulatum* but there are concerns that it may have been lost from some historic locations. Similarly, there have been no quantitative studies into the habitat preferences of *C. hastulatum* in Great Britain. An extensive survey was made of ponds in Aberdeenshire in 2016 and the presence or absence of *C. hastulatum* was analysed in relation to a wide range of habitat variables. The results showed that *C. hastulatum* was associated with eight habitat variables: positively correlated with water and silt depth, *Juncus acutiflorus, Carex rostrata* and *Sphagnum,* and negatively correlated with *J. bulbosus* and floating and emergent vegetation cover. These results provide a preliminary indication of *C. hastulatum*'s preferences in north-east Scotland which will aid further investigations, including the current British Dragonfly Society project on *C. hastulatum* (British Dragonfly Society, 2019).

Introduction

Coenagrion hastulatum (Northern Damselfly) is a widespread and abundant species in northern Eurasia and is often the most common blue damselfly in much of boreal Europe, occurring in both standing and running waters (Kaunisto *et al*., 2015). Towards the south and west of its range, it is associated with elevated or bog-like sites (Dijkstra, 2006). In Britain it is restricted to an area centred around the Cairngorms, extending east to Aberdeenshire and north to Inverness-shire, where it seems to favour sedge-fringed pools. Despite IUCN designation of Least Concern, it is classed as Endangered on the British Red

List. It also appears on the Scottish Biodiversity List (NatureScot, 2020), under the Nature Conservation (Scotland) Act (2004), and it is a key species in the Cairngorms Nature Action Plan (Cham *et al.*, 2014).

In Scotland, *C. hastulatum* larvae attain a maximum length of around 17-18 mm, usually after two year's growth (Smith & Smith, 1999). The foraging mode of *C. hastulatum* larvae can shift between sit-and-wait and active predation. This shift is related to prey density, with the active strategy needed when prey items are scarce (Johansson, 1991). Their diet includes most invertebrates of a size that can be handled, including cannabalism of smaller larvae. A further study found that their activity was generally low, mostly using the sit-and-wait strategy (Johansson, 1993). They seemed to prefer a microhabitat close to the water's surface, and it was proposed that this might be beneficial for the larvae because the higher temperatures there would enable faster metabolism (Johansson, 2000). It might be that this microhabitat also has other advantages, such as a reduced risk of predation and competition, including from larvae of the common dragonfly *Aeshna juncea*, which utilises intermediate depths to forage (Johansson, 2000). This latter species seems to have a negative impact on the feeding strategy of *C. hastulatum* (Johansson, 1991).

In a review of *C. hastulatum* in Scotland, Marren & Merritt (1983) noted that all known localities lie within the continental rather than the oceanic part of northern Scotland. That is, between the 0.6 °C February minimum and the 2.5 °C January mean isotherms, and between the 14.0 and 14.5 °C July mean isotherms. One of the authors (JD) has observed them swimming amongst the sub-surface vegetation and/or *Sphagnum* at the edge of ponds, even in early January, when larvae of another species found in these ponds, *Pyrrhosoma nymphula* (Large Red Damselfly), were completely inactive. On emergence, the pale exuviae can be found typically on stems 2 - 4 cm above water, although sometimes they are just at the water surface, or on heather twigs overhanging the water's edge.

Due to a lack of regular long-term recording of *C. hastulatum* in Scotland, little is known about the species' requirements, the extent of its distribution, or the size of its populations. Casual observations in the past, as well as recent more focussed survey work, suggest that, where it does occur, populations are mostly small and restricted to a small number of sites (Daguet *et al*., 2008). Occasionally, abundant populations are found (JD, *pers. comm.*), but the factors leading to these local abundances are not clear. Smith & Smith (1999) noted that, for *C. hastulatum*, there is a strong relationship with long-established forests of Scots pine (Plate 1) and birch, while Flenner (2007) noted that odonate species that disappear when a forest is harvested around a lake or pond, do not seem to re-colonise easily and that the communities that do result usually differ in

Plate 1. Tandem pair of *Coenagrion hastulatum* on Scots pine.

species composition and structure. Furthermore, Suhonen *et al.* (2010) found that extinction rates of odonates were higher in presumed 'low quality' than in 'high quality' habitats and so suggested that a good understanding of habitat quality is crucial to the conservation of Odonata in heterogenous and changing landscapes.

It has been proposed that climate change may result in a contraction of suitable sites for cold-climate adapted species (Termaat *et al.* 2019). Projections show that areas of endemism for five taxonomic groups (including vascular plants) in the Austrian Alps will, on average, experience a 77 % habitat loss, even under the weakest climate change scenario (+1.8 ^{o}C by 2100) (Dirnbock *et al.,* 2011). This is significant, as dragonfly species richness appears to be positively associated with species richness of vascular plants (Sahlen & Ekestubbe, 2001). There is some relevant evidence of the possible effect of climate change in the steady move northwards in the last decade of *Coenagrion puella* (Azure Damselfly) in Scotland, which one of the authors (JD) has recently observed sharing sites with *C. hastulatum* in Aberdeenshire and which also now occurs in Perthshire (Paul, 1987). This may indicate the potential for increased competition in their shared sites. Van Doorslaer & Stoks (2005) found that the patterns of thermal plasticity in embryonic traits showed that *C. hastulatum* was apparently more successful than *C. puella* at lower temperatures.

There have been no quantitative investigations into the comparative habitat preferences of *C. hastulatum* in Scotland or elsewhere, and so the key characteristics of occupied ponds remain unknown. It is thus clear that there is a need for a better understanding of the biology and ecology of this species in Scotland (Blyth, 2014). The purpose of this study is to determine the habitat preferences of *C. hastulatum* in Scotland by comparing the habitat conditions in pools within the known Scottish range, where *C. hastulatum* does and does not occur. It is thus hoped to be able to provide information for conservation workers and land managers of how best to manage freshwater habitats to favour the species. It should also help improve the effectiveness of surveys to identify new occupied pools, so that its true range and population status can be established.

Methods

Study sites

Twenty-three ponds were used for the study in 2016, twelve where *Coenagrion hastulatum* was present (Plates 2, 3) and eleven where *C. hastulatum* was not found (Plates 4, 5). The study sites were in three distinct geographical areas of Deeside in Aberdeenshire, east of the Cairngorms mountain range (Fig. 1). The ponds were composed of eight sites in Braemar, eight around Dinnet and nearby Cambus O May, and a further seven at Glen Tanar, near Aboyne.

Ponds were first surveyed in early spring on various dates between 23 February and 16 April 2016, prior to the annual emergence of any odonates, to confirm the presence or absence of *C. hastulatum* and to record evidence of breeding of other odonate species at the sites. It is important that ponds which do and do not contain larvae are identified accurately.

Sampling was carried out at regular areas around the edges of the ponds for 60 minutes using a plastic sieve to agitate and sweep the water column. At smaller ponds it was possible to cover all areas of the circumference within this time; at large ponds visually varied areas of habitat were sampled with as much coverage of the overall circumference as possible within the 60-minute time-period. This meant the same effort was applied to sampling at each pond regardless of size. There were areas of some ponds that were physically inaccessible. Pools were classed as positive if larvae of *C. hastulatum* were found within the 60-minute sampling period. A grid reference, general habitat descriptions and relative abundance of *C. hastulatum* (e.g. absent, rare, occasional, frequent) were recorded for each pond (Table 1). Contents of sieves were rinsed into a container with a white base and identified on site with the aid of a x10 magnifying

Plate 2. Fairy Lochan, Glen Tanar, Aberdeenshire. *Coenagrion hastulatum* was present at this site.

Plate 3. Ess Pond, Glen Tanar, Aberdeenshire. *Coenagrion hastulatum* was present at this site.

Plate 4. Drum Burn Pond, Aberdeenshire. *Coenagrion hastulatum* was absent at this site.

Plate 5. Cambus O May pond, Aberdeenshire. *Coenagrion hastulatum* was absent at this site.

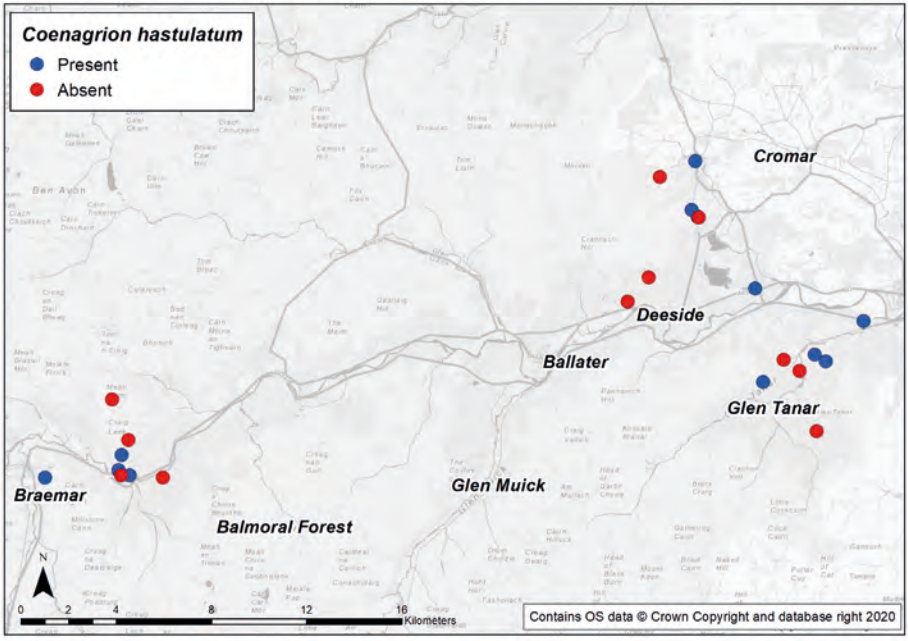

Figure 1. Distribution of the surveyed ponds across Aberdeenshire. *Coenagrion hastulatum* was absent from the ponds marked in red and present at the ponds marked in blue.

hand loupe (hand lense). On the occasions where identification in the field was not possible, field notes were made and photographs taken for identification later. Odonata and Ephemeroptera were identified to species level. All fauna were identified to species where possible and then returned to the areas they were taken from. Standard biosecurity measures were adhered to by using a clean set of equipment for each pond sampled.

Habitat variables

A second phase of surveys took place in June 2016 during the peak emergence and breeding time for *Coenagrion hastulatum*. Quadrats were used to survey four locations per pond. Quadrats (2 m x 5 m) were placed longitudinally with respect to the pond's edge. Measurements taken were water depth, substrate composition, distance from the tree line, tree overhang, topographic shelter, abundance and composition of terrestrial and aquatic (floating and emergent) vegetation, and water clarity. The presence of a visible in-flow and out-flow was recorded for each pond. Water samples were collected with help from volunteers on 3 July and 4 July 2016, both days being warm and dry. The samples were kept cool during transportation to the laboratory, where they were

Table 1. Ponds surveyed and the relative abundance of *Coenagrion hastulatum*.

Pond/grid reference	*Coenagrion hastulatum*	
	Status in each pond	No. quadrats in which present (total = 4)
	Frequent	
Fairy Lochan NO 48280 96100		2
Sandpit NJ 43110 02160		3
	Occassional	
Berry's Burn NO 48760 95820		3
Ess NO 50340 97490		1
Betty's NJ 43370 01880		2
Logie Coldstone curling pond NJ 43270 04210		2
Dinnet curling pond NO 45790 98860		2
Corrie Feragie NO 15920 90930		2
	Rare	
Burn of Boonie NO 46120 94950		1
Mast NO 19470 91020		1
Felagie NO 19140 91880		1
Car Park NO 19000 91240		1
	Absent	
Queen's Road NO 46980 95880		0
Drum NO 48376 92871		0
Horsetail NO 47650 95410		0
Barglass NJ 41780 03540		0
Cambus (2) NO 40420 98310		0
Cambus (5) NO 41310 99330		0
Pine Ring NJ 43420 01840		0
Ballochbuie Dam NO 20880 90930		0
Meall Gorm NO 18740 94220		0
Gull NO 19420 92520		0
A93 NO 19130 91030		0

filtered and analysed using a Skalar autoanalyser (SKALAR Sanplus Analyzer, Breda, The Netherlands) within 3 days of collection. Samples were analysed for nitrate (NO_3-N), ammonium (NH_4-N), total nitrogen (N), total organic nitrogen, total phosphorus, total organic phosphorus, dissolved organic matter (DOC), electrical conductivity and pH.

The distance used to record the presence of named peripheral plants was chosen as 0.5 m over water and 1 m over land, as during the preliminary phase larvae had been found close to the edge. Emergent vegetation amount and density were recorded for up to 5 m into the pond. Measurements of water depth were taken close to the pond edge at the surveyor's arm length.

Other than for collecting water samples, the fieldwork was carried out by one experienced surveyor (JD) and the method of survey was consistent throughout

the study.

Data analysis

Data were analysed using a Generalised Linear Mixed Model (GLMM) with the logit link function, distribution set to binomial and the dispersion parameter set to 1. A GLMM was chosen to identify the best combination of independent variables linked with the presence of *Coenagrion hastulatum.* Analyses were carried out on a quadrat basis but with pond entered as a random (blocking) factor. This was because *Coenagrion hastulatum* is patchily distributed around those ponds where it occurs, being found in between one and three (mean = 1.75) of the four quadrats. Plant species occurring in fewer than 10% (i.e. <4) or more than 90 % (>32) of the total number of quadrats were not analysed. The remaining variables (Table 2) were tested for normality and transformed where needed: nearest inhabited pond was square root transformed; pond area, water depth, silt depth and distance to the tree line were all log transformed. To reduce dimensionality, a Principal Component Analysis (PCA) was performed on the water variables and, as most of the variation was captured by PCA1, these values were used to represent water quality. All analyses were carried out using Genstat version 19.

Results

There is evidence that some of the variables show a degree of inter-dependence and so it is appropriate to consider them both together and separately when coming to an assessment of their relationship to the presence or absence of *Coenagrion hastulatum*.

The presence of *C. hastulatum* was associated with eight of the variables tested (Table 3). There was a strong significant positive association ($P<0.001$) with water depth (Fig. 2), silt depth (Fig. 3) and the presence of *Carex rostrata, Juncus acutifloris* and living *Sphagnum* (Table 3). Thus *C. hastulatum* was found where the silt and water were deeper on average and where these plant species were more abundant. There was a strong significant negative association with *J. bulbosus* ($P<0.001$) (Table 3), and a rather weaker one with floating (Fig. 4) ($P<0.01$) and emergent ($P<0.05$) vegetation cover (Fig. 5). Of the associated plant species, *C. rostrata* and *J. acutiflorus* were twice as likely to be present at breeding sites of *C. hastulatum* while the reverse trend was shown for *J. bulbosus*. There was no collinearity between water and silt depth and any of these plant species. However, *Sphagnum* was positively associated with deeper silt (ANOVA $F = 5.31$, $P = 0.031$).

Table 2. Variables analysed for correlation with the presence of *Coenagrion hastulatum*.

Variable	Description
Geophysical	
Pond area	Continuous variable (m^2)
Nearest inhabited pond	Distance to the nearest pond inhabited by *Coenagrion hastulatum* (m)
Exposure	Dummy variable (0 open, 1 tree shelter, 2 hill shelter, 3 tree and hill shelter)
Silt depth	Continuous variable
Fine organic silt	Binary variable (presence/absence)
Fine mineral sand	Binary variable (presence/absence)
Coarse mineral sand	Binary variable (presence/absence)
Coarse mineral gravel	Binary variable (presence/absence)
Coarse organic debris	Binary variable (presence/absence)
Water	
Depth	Continuous variable (water depth cm)
Quality	Combined variable (PCA1), see methods section
Inflow	Binary variable (presence/absence of a visible inflow)
Outflow	Binary variable (presence/absence of a visible outflow)
Vegetation	
Distance to trees	Continuous variable (distance from pond edge to nearest trees, m)
Conifer dominance	Binary variable (trees around the pond dominated by conifer species, yes/no)
Emergent vegetation cover	Continuous variable (%)
Floating vegetation cover	Continuous variable (%)*
Sphagnum	Binary variable (Presence/absence)*
Sedges/rushes	Dummy variable (0 absent, 1 rare, 2 frequent, 3 dominant) for three species: *Carex rostrata*, *Juncus acutiflorus* and *J. bulbosus*.

Table 3. Associations between the presence of *Coenagrion hastulatum* and habitat variables as analysed by Generalised Linear Mixed Models. Th effects are annotated with the level of statistical significance: *(P < 0.05), **(P<0.01), ***(P <0.001).

Fixed term	Effect	Wald statistic
Water depth (cm)	Positive***	354.13
Juncus bulbosus	Negative***	60.82
Silt depth (cm)	Positive***	31.85
Juncus acutiflorus	Positive***	23.20
Sphagnum spp.	Positive***	13.09
Carex rostrata	Positive***	9.44
Floating vegetation cover (%)	Negative**	8.01
Emergent vegetation cover (%)	Negative*	5.52

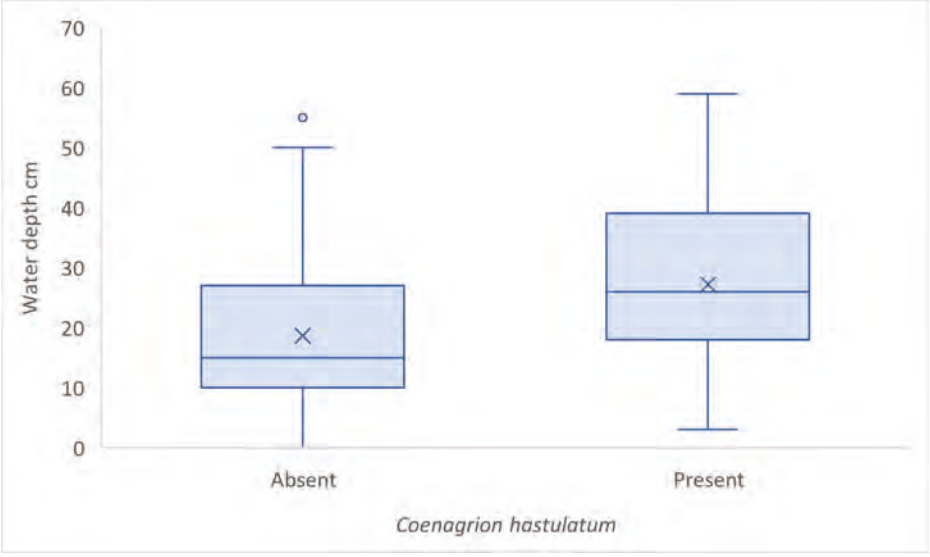

Figure 2. Association between water depth and the absence or presence of *Coenagrion hastulatum* larvae. The blue box represents the upper and lower quartiles (i.e. 25 % of data that is greater and 25 % of data that is lower than the median). X, mean; horizontal line, median; extent of vertical line indicates minimum and maximum values, except for outlying data points (O).

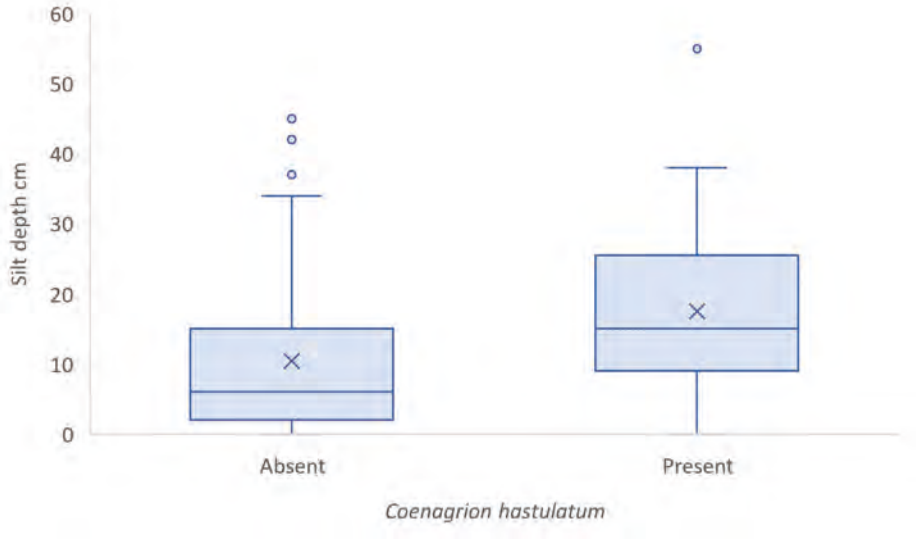

Figure 3. Association between silt depth and the absence or presence of *Coenagrion hastulatum* larvae. The blue box represents the upper and lower quartiles (i.e. 25 % of data that is greater and 25 % of data that is lower than the median). X, mean; horizontal line, median; extent of vertical line indicates minimum and maximum values, except for outlying data points (O).

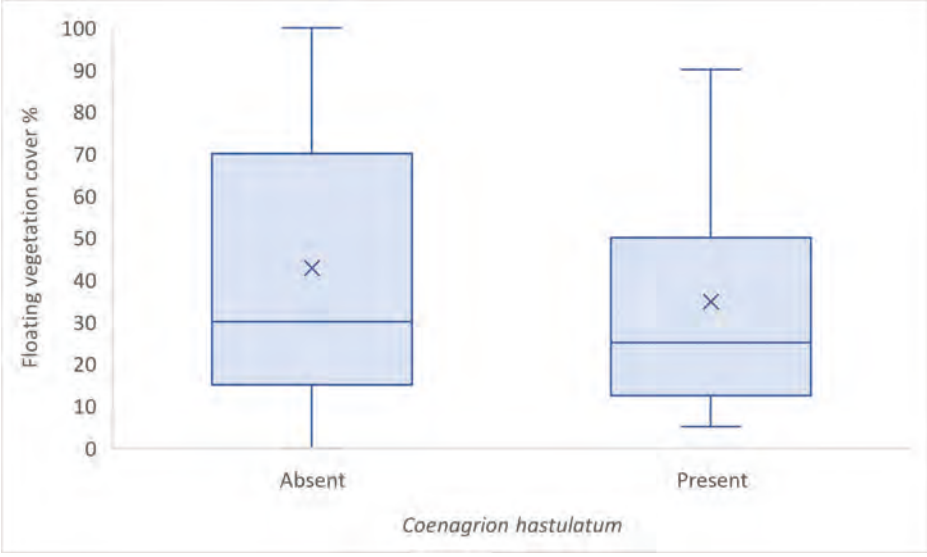

Figure 4. Association between floating vegetation cover and the absence or presence of *Coenagrion hastulatum* larvae. The blue box represents the upper and lower quartiles (i.e. 25 % of data that is greater and 25 % of data that is lower than the median). X, mean; horizontal line, median; extent of vertical line indicates minimum and maximum values.

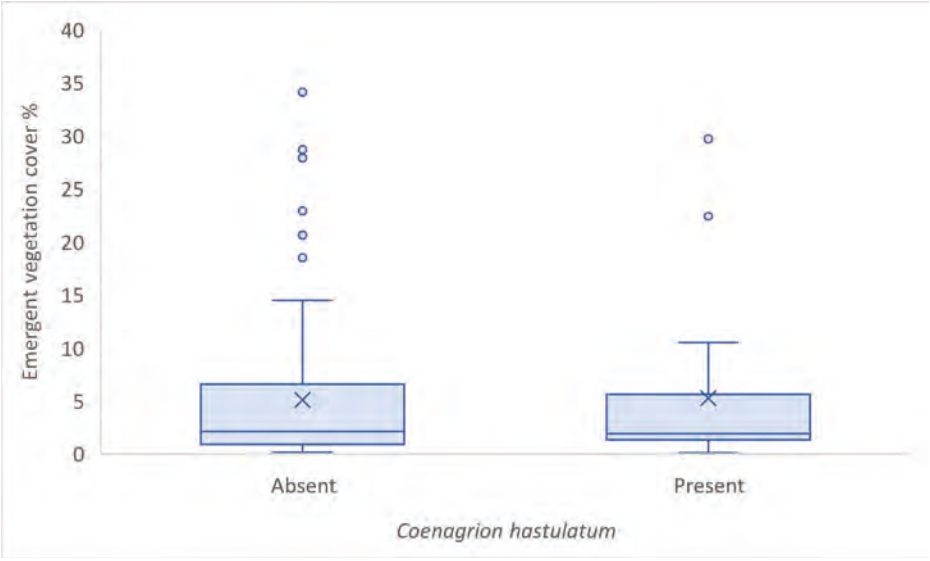

Figure 5. Association between emergent vegetation cover and the absence or presence of *Coenagrion hastulatum* larvae. The blue box represents the upper and lower quartiles (i.e. 25 % of data that is greater and 25 % of data that is lower than the median). X, mean; horizontal line, median; extent of vertical line indicates minimum and maximum values, except for outlying data points (O).

Discussion

This study has shown, in north-east Scotland, both positive and negative correlations between the presence of *Coenagrion hastulatum* and several pond features. Deeper ponds, with deep silt and, to a lesser extent, the presence of *Carex rostrata, Juncus acutiflorus* and *Sphagnum* are more likely to host *C. hastulatum*, whereas ponds with prominent *Juncus bulbosus* and large amounts of emergent and floating vegetation are less likely sites. No adult *C. hastulatum* or their exuviae were seen in the follow up survey phase in summer 2016 at pools where no *C. hastulatum* larvae had been found in the initial survey in early spring 2016 and therefore the initial survey was considered an accurate representation of the presence or absence of larvae. However, MacKenzie *et al.* (2002) stated that studies using presence-absence data are liable to underestimate true occupancy at sites due to imperfect detection. They suggested that, for a rare species, it is more efficient to survey more sampling units less intensively, while for a common species fewer sampling units should be surveyed more intensively (MacKenzie & Royle 2005). It was not possible to cover all of the edges of some ponds as they were either physically inaccessible or the waterbody was too large for the sampling time allowed. However, it is believed that the areas selected for sampling were sufficient to cover the variety

of microhabitat and give a true representation of each pond.

It is noted that there may be some bias as a result of the survey being carried out along the edges of ponds. Thus there may be plants which naturally colonise the edges but not necessarily the middle of ponds but this was unavoidable in practice, as there was no other realistic way of carrying out the survey. One metre over land was deemed to be a likely distance that vegetation may influence aquatic oviposition sites and territorial choices for males. It also allowed for plant species to be recorded where there may be some ambiguity as to the definition of the water's edge, as some ponds can have either very shallow drawdown zones or waterlogged banks. Hence some plant species recorded could be perceived both as in the water and also on the bank.

Although a wide range of geophysical variables were measured, our results show correlations only at a micro-habitat level. A further survey in 2017 measured a subset of plant species and abundance and density, as well as the expanse of edging plants, but no significant correlations were found other than those recorded in the results from 2016. Measurements of water depth were taken fairly close to the pond edge but in some cases water depth further into the pond was deeper. Also summer water levels are likely to be lower than in winter, especially where dense vegetation at ponds is present during the summer. Our results corroborate Ott's suggestion that *C. hastulatum* is sensitive to lowered water levels (Ott, 2010). Deeper water is likely to stay cooler in warm summer conditions and warmer in cold winter conditions, although this is unlikely to explain why *C. hastulatum* prefers deeper water as the larvae are typically found nearer the surface. However, it may be that greater water depth has a benefit when thick ice forms in winter, allowing enough remaining depth for the larvae to avoid competition with other species.

The negative correlation between *C. hastulatum* and *J. bulbosus* is perhaps unsurprising, as *J. bulbosus* is associated with much shallower habitats and is typically a plant of wet heaths, bogs and wet track-ways (Rose, 1989). In contrast, *J. acutiflorus* is found on deep, wet, acid to neutral soils in mires (Averis, 2013) and was often next to *C. rostrata* at the edge of pools where *C. hastulatum* larvae were found. In winter, these long stems break down and form floating rafts next to the *sphagnum* edges. We found larvae just underneath dead stems or amongst the more open areas of remaining vertical stems and under sphagnum ledges. Smith & Smith (1999) stated that *Sphagnum* species are often present but apparently have no particular significance for *C. hastulatum*. However, in the present study, sphagnum was present at nearly all *C. hastulatum* sites, but not all sites with sphagnum had *C. hastulatum*. It appears that a combination of variables is key: sphagnum is important but only when combined with other factors such as water depth and the presence of *J.*

acutiflorus and *C. rostrata*, and where floating and emergent vegetation does not completely cover the water surface. In the present study a correlation was found between silt depth and sphagnum presence. It is possible that, over time, dead sphagnum contributes to the silt depth and this may explain the correlation.

The British National Vegetation System (NVC) classifies and describes natural habitat types according to the vegetation they contain. Bog-pool communities, described as sub-groups of the mire communities in the JNCC National Vegetation Classification (NVC) Field Guide to Mires and Heaths (Elkington *et al.*, 2001), provide the closest description of the habitat most typically associated with *C. hastulatum* in the highland areas of north-east Scotland, especially M4 - *Carex rostrata – Sphagnum recurvum* mire, also specified as *Carex rostrata – Sphagnum fallax* mire (Averis, 2013). However, it should be noted that there can be overlap with other communities that may be nearby. It is interesting to note the following statement regarding habitat M4 (Elkington *et al.*, 2001): "… the vegetation may be very stable provided the high-water table and modest irrigation are maintained". This statement may provide vital guidance regarding the goal of maintaining water table levels, as the basis for supporting the flora associated with *C. hastulatum* habitat. Furthermore, Larson & House (1990) suggested that odonate communities in Newfoundland are characteristic of large, stable, vegetated bog pools, with stability of water levels believed to be the principal factor determining community structure. Two of the variables measured during the present study were the presence of in-flow and out-flow, where present. However, neither of these variables were correlated with the presence of *C. hastulatum*. Although these features may contribute to the stability of the water level at individual sites, they are not the only means whereby an effective stability can be achieved. However, it is likely that most sites will be soligenous in nature, even if the source feeding the site is not obvious.

Regular management to reduce the extent of floating and emergent vegetation is recommended and fixed-point photographic evidence may be utilised at ponds where *C. hastulatum* is known to be present in order to monitor and maintain appropriate conditions. It is not recommended that *J. bulbosus* is removed from existing pond habitats, as it is already rare at existing *C. hastulatum* sites. However, its presence may indicate that such a habitat is unlikely to be an ideal site for extension of an existing waterbody when considering encouraging *C. hastulatum* to a site.

It is interesting to note that *C. hastulatum* will use both natural and artificially created ponds (e.g. curling ponds) so long as these develop a similar plant community and water depth. It is suggested, therefore, that land managers and conservationists prioritise both of these habitat types (e.g. NVC M4 and

curling ponds) when maintaining or creating habitat for *C. hastulatum*. When creating a new site, the depth of the pond must be considered as well as how that site will be naturally colonised in terms of nearby vegetation, and also the natural irrigation and water loss that it is likely to experience especially under summer conditions. An ongoing regular review and maintenance plan is highly recommended.

Recommendations for land managers:

1. Maintain and increase where possible NVC type M4 - *Carex rostrata* – *Sphagnum recurvum/fallax* mire.

2. Consider removing floating vegetation and emergent vegetation when they exceed 90 % or 30 % cover respectively within 5 m of the waters' edge.

3. Monitor water levels and ideally maintain 20-40 cm summer depth.

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Observations on a new colony of *Ischnura pumilio* (Charpentier) (Scarce Blue-tailed Damselfly): the first record for West Sussex

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Summary

In June 2020 *Ischnura pumilio* (Scarce Blue-tailed Damselfly) was recorded for the first time in West Sussex. This was not an isolated record; a colony had become established on a recently cleared wetland habitat near Sompting. This paper describes the find and provides observations of the colony over the summers of 2020 and 2021. The habitat has been shown to have exceptionally high mid-day water temperatures compared to surrounding habitat. The management regime for the habitat has meant that the area has proved to be transitional for the species. Particular features of this transitional population are:

- The population appears to have two generations.
- The female numbers are much lower than in permanent sites especially in the second year, 2021.
- The androchrome female, which is rare in Europe, has been observed frequently.
- Males appear to be much more loyal to the site and remain even when the females have mostly disappeared.
- Males can be individually recognised by the patterning on the taillight. Is this a factor in sexual attraction?
- There was one observation of oviposition underwater, which is extremely rare in this genus.

Introduction

Ischnura pumilio (Scarce Blue-tailed Damselfly) is widespread over most of Europe except the far north. It extends west to the Atlantic archipelagos and east into China (Dijkstra *et al*., 2020). In the British Isles it is found in Ireland, Wales and Southern England; it is locally common in England in the West Country, Dorset and the New Forest but very local elsewhere (Cham *et al*.,

2014). Boudot & Kalkman (2015) stated that *I. pumilio* is a pioneer species found in shallow sparsely vegetated waters such as newly created and ephemeral ponds. Furthermore, they highlighted the species' "strong dispersal power", this being one of very few species to have colonised the archipelagos of the Azores and Madeira, which are 1,000 and 600 miles from mainland Europe respectively. Allen *et al*. (2010) summarised the key habitat requirements as "muddy substrate with some open ground, turbid water and low levels of shade. It is known to thrive in areas where man constantly adapts the water management; rice paddies are a well-known habitat but mining areas and other regularly cleared shallow water bodies are often colonised.". The only previous Sussex record was from East Sussex, from Crowhurst and Abbotts Wood near Eastbourne (East Sussex) in 1900 (Belden *et al*, 2004). The nearest known colonies to the one in West Sussex are in the New Forest in Hampshire, which is 60 miles to the west.

Site

Sompting Brooks (British Grid Reference TQ1604) is an area of lowland flood plain (average approximately 4.0 m a.s.l.) of approximately 100 hectares. It is enclosed by the A27 trunk road to the north, the rail link between Brighton and Portsmouth to the south and the built-up areas of Worthing and Sompting/ Lancing to the west and east respectively (Fig. 1). The area is owned by the Sompting Estate Trust. In 2019, the Trust, in conjunction with the Ouse and Adur Rivers Trust (OART), with funding from the National Lottery Heritage Fund and Rampion Fund, and with the backing of the Environment Agency, commenced work on a project to improve/create habitat on the arable farmland which dominates the area. From the dragonfly perspective, the main interest was the creation, by diversion, of a completely new stretch of stream, which was created during the summer of 2019 (Plate 1A), hereinafter referred to as the Cut. It received diverted water in July of that year, having passed through two silt-traps provided to trap run off from the A27.

In summer 2019, the OART ecologists recorded the initial colonisation of dragonflies, which included *Orthetrum cancellatum* (Black-tailed Skimmer) quickly moving in, in spite of the virtual absence of vegetation. Other species, such as *Libellula depressa* (Broad-bodied Chaser) and *Sympetrum striolatum* (Common Darter) must have visited at this time to oviposit as exuviae/ tenerals of both were present in early summer 2020, when other 'expected' early colonisers were recorded, including *Pyrrhosoma nymphula* (Large Red Damselfly) *Coenagrion puella* (Azure Damselfly), *Ischnura elegans* (Blue-tailed Damselfly), *Anax imperator* (Emperor Dragonfly) and *Libellula quadrimaculata* (Four-spotted Chaser). On the 19 June 2020, Tom Forward, an ecologist working for OART, was sweep-netting to record insects along the stream banks

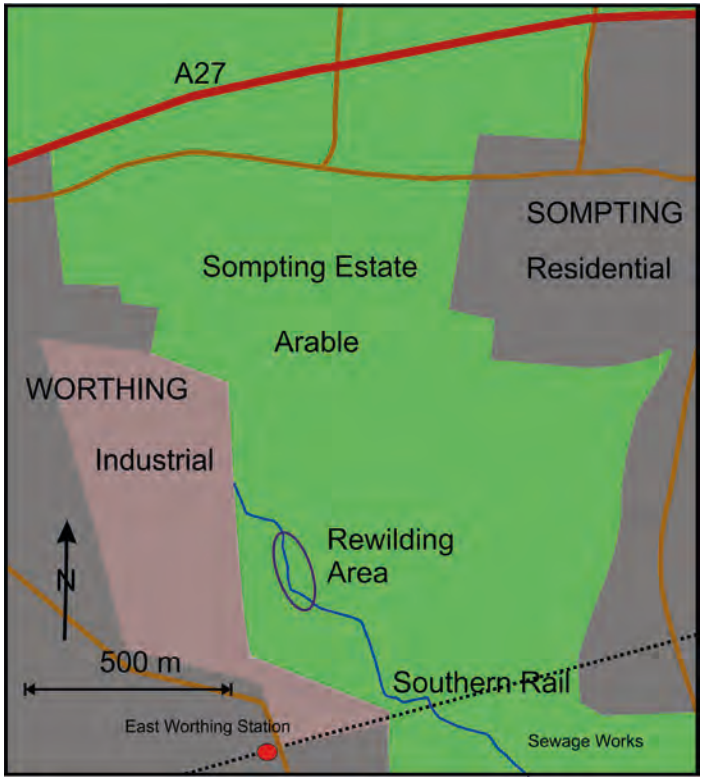


Figure 1. Location of the Sompting Estate, showing the position of the Rewilding area where the Cut is located.

and caught a male *Ischnura pumilio*. David Sadler (DS) visited the site on 22 June 2020 and confirmed the record, which is the first for this species in West Sussex.

Methods

Following the discovery, a stretch of approximately 120 m of the Cut was visited regularly during the months of May to September in 2020 and 2021. There was a period in early July 2020 when access was forbidden while an archaeological dig took place. The Cut was patrolled in both directions, including the adjacent open banks, and a total estimated number of individuals of both sexes and mating pairs made. The time spent on site for each visit was a minimum of two hours. It was noticed that individual males had varying markings on abdominal segments 7-10 (taillight). Close digital photographs were taken of the taillight of

A

B

C

D

Plate 1. The Cut (A) in August 2019, (B) in August 2020, (C) in June 2021, (D) in August 2021.

all individuals and these were later analysed in detail. A note was also made of the different female morphs.

Another factor that was considered was water temperature. This was measured using standard commercial water thermometers with remote and internal sensors. Two different thermometers were used for measurements and the results averaged. Measurements were taken from a number of points along the Cut, where the highest concentrations of adult *Ischnura pumilio* were found. To provide a comparison, temperatures were taken contemporaneously at nearby ponds and at Brooklands Park, Worthing.

Observations

It is important to note from the outset that *Ischnura pumilio* is a very small, unobtrusive and mobile insect that is far from easy to survey. It requires sunny, warm and fairly calm conditions to have any chance of success. The numbers

given in this paper must, therefore, be considered as a conservative estimate of the true situation.

The first and last dates for observations were:

- 2020 –
    - 19 June – first record
    - 15 September
- 2021 –
    - 30 May
    - 3 September – access to the Cut not available after this date

The pattern of the population numbers was quite different in the two years of observations (Table 1). In 2020 the population was at its highest in August (11.4 total individuals per visit), whilst in 2021 the most populous month was June (12.1 total individuals per visit).

In 2020 small numbers were recorded through June until the end of July when they almost disappeared. Then, in early August, teneral insects and an exuvia (Plate 2) were found and numbers steadily increased until, on 12 August, 30 individuals were observed. In 2021 the situation was quite different, with large numbers (up to 30 individuals) observed in early June, with numbers then gradually declining until 23 and 24 July when no observations were made. On 10 August small numbers started to appear, with a maximum of seven individuals recorded on 24 August.

This different monthly pattern of activity was also reflected in the mating pairs observed. The total number of pairs recorded was similar in the two years; however, in 2020 the majority (eight of nine) were observed in August, whilst in 2021 the majority (six of eight) were seen in June. Perhaps the most significant difference between the two years was the reduction in the number of sightings of oviposition. There were 20 sightings in 2020, the majority at the end of the season, but only two in 2021, the last being on 19 July (Table 2).

Males

Six main areas of variation were noted in the taillight (Table 3, Plates 3,4). The markings were prominent even on teneral specimens (Plate 5).

From the photographic analysis a total of 60 individual males were recorded in 2020 and 73 in 2021. This analysis further showed that there were no repeats over the two years, implying that all males have different markings. Furthermore, in both 2020 and 2021 those males that appeared later in the year (August

Table 1. Summary of observations of *Ischnura pumilio* at Sompting. The totals include mating pairs.

	Visits	Totals (both sexes)	Totals per visit	Males	Females	Females per visit	%age females	Mating pairs
2020	33	249	7.5	206	43	1.3	17%	9
2021	37	233	6.3	216	17	0.5	7%	8
Totals	70	482	6.9	422	60	0.9	12%	17
				2020				
June	4	12	3.0	11	1	0.3	8%	0
July	9	44	4.9	40	4	0.4	9%	1
August	13	148	11.4	121	27	2.1	18%	8
September	7	45	6.4	34	11	1.6	24%	0
Totals	33	249	7.5	206	43	1.3	17%	9
				2021				
May	3	22	7.3	21	1	0.33	5%	0
June	12	145	12.1	134	11	0.92	8%	6
July	11	20	1.8	19	1	0.05	5%	0
August	10	45	4.5	41	4	0.40	9%	2
September	1	1	1.0	1	0	0.00	0%	0
Totals	37	233	6.3	216	17	0.46	7%	8

onwards) had greatly reduced (Plate 4C) or non-existent ‘D’ markings.

On many occasions the males were recaptured photographically and, from this information, it was possible to record the minimum life spans of individuals. Most were recorded over a period of about two weeks, with two individuals lasting at least 26 days, one of which was first seen as a full blue adult on first capture, indicating that it was probably already at least a week old.

Females

Sanchez–Guillen *et al*. (2020) stated that the females of *I. pumilio* are dimorphic consisting of androchrome (similar to the male) and gynochrome colour morphs. However, the juvenile androchrome is unique in the genus in that it is has the ‘aurantiaca’ (orange) form, as does the gynochrome.

Plate 2. An exuvia of *Ischnura pumilio* found with an emerging adult.

Relatively small numbers of females were observed over the study period. There was an overall average of 12% of the total population; 17% in 2020 but only 7% in 2021. The highest monthly percentage of females recorded in 2020 was 24%, whereas in September 2021 no females were recorded, the highest percentage being in August (9%). A note of caution with these figures is that males are hard enough to observe but females even more so, especially the adult gynochrome which blends in well with the vegetation.

Two juvenile 'aurantiaca' forms were recorded, both in 2020 (Plates 6, 7). The 'aurantiaca' form matures into either the blue androchrome (Plate 8) or the brown-green gynochrome (Plate 9). The majority of the mature individuals recorded were gynochrome; indeed no juveniles or androchromes were recorded in 2021 (Table 4).

Mating & Oviposition

The preferred plant for oviposition was *Callitriche* sp. (Starwort.). Other plants utilised were *Apium nodiflorum* (Watercress), *Lemna* sp. (Duckweed),

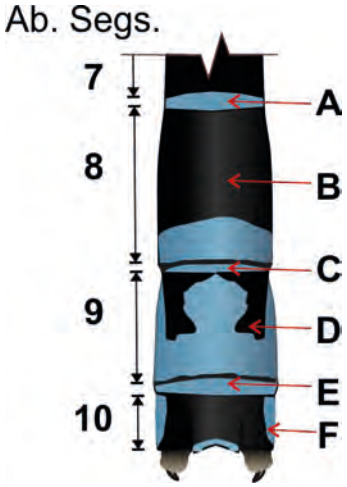


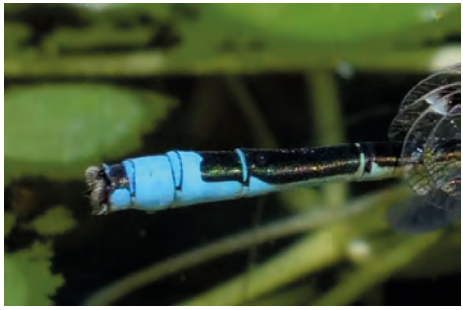
Plate 3. Abdominal segments 7-10 of a male *Ischnura pumilio* showing the areas where there is variation in the taillight.

Table 2: The number of recordings of oviposition in 2020 and 2021. The week number is the week of the year. Week 25 started on 15 June 2020 and on 14 June in 2021; week 38 started on 14 September in 2020 and on 13 September in 2021.

Week number	Year	
	2020	2021
25		1
26		
27		
28		
29		
30	1	1
31		
32	2	
33	3	
34	5	
35	4	
36	1	
37	3	
38	1	
Total	**20**	**2**

A

B



C

Plate 4. The taillight of males of *Ischnura pumilio*. (A) with extensive black markings, (B) with a prominent 'D' marking, (C) with a greatly reduced 'D' marking, which feature predominated in the late summer of both years.

Table 3. Variability of the male taillight markings on abdominal segments 8-10 of a male *Ischnura pumilio*, as indicated in Plate 3.

A	Junction of abdominal segments 7-8	Variable in depth
B	Border of black marking on abdominal segment 8	Variable and often asymmetrical
C	Junction of abdominal segments 8-9	Variable amounts of black on borders
D	Black markings on abdominal segment 9	Ranging from non-existent to almost covering the segment. This marking can also be asymmetrical
E	Junction of abdominal segments 9-10	Variable amounts of black on borders
F	Abdominal segment 10	Blue sides variable in shape

Plate 5. A teneral male of *Ischnura pumilio* showing the taillight markings. Photograph by Paul Winter.

Table 4. Numbers of female morphs of *Ischnura pumilio* at Sompting.

	2020	2021
Immature	2	0
Mature		
Gynochrome	34	17
Androchrome	7	0

Phragmites australis (Common Reed) and algae. Both males and females were observed in copula whilst in their immature stages (Plate 10). Without exception, females were observed ovipositing alone. In most cases, passing males ignored the female and, if a male did show interest, then the female would fly off. However, on three occasions the ovipositing female was caught by a male. Twice the female carried on ovipositing (Plate 11), manoeuvring to try to break the male's grasp; once the female relented and the pair flew off. On a single occasion a female was observed ovipositing completely underwater (Plate 12), which we believe to be the first such observation in the UK.

Water Temperature

In June 2020, the Cut certainly conformed to the habitat requirements of *Ischnura pumilio* noted by Allen *et al*. (2010) (Plate 1B) but so too do many other newly created habitats that do not attract this very local species. One of the factors which differentiated the Cut was water temperature (Table 5).

The temperatures were all taken over a range of time from 11:38 until 15:45 BST. Time of year during the adult flying period appears to make little difference, for example, the average temperatures were 25.6°C on 31 May 2021 and 26.0°C on 14 August 2021. On 6 September 2020 the thermometers were left overnight, when the minimum temperature recorded was 11.9°C.

Discussion

Ischnura pumilio has been thought to be a highly transient species that colonises newly formed habitat but, as the habitat changes, only survives for a few years (Grand & Boudot, 2006). Indeed, Boudot & Kalkman (2015) stated that the population tends to increase over the first few years but then declines as the vegetation becomes more dense and other species move in. This appears to be the case at the Cut. In June 2021, water levels were generally lower than in the

Plate 6. A teneral female of *Ishnura pumilio* which could mature in to either the androchrome or the gynochrome.

Plate 7. A typical “aurantiaca” immature female of *Ischnura pumilio.*

Plate 8. An androchrome (blue) female of *Ischnura pumilio*.

Plate 9. A gynochrome female of *Ischnura pumilio*.

Table 5. Water temperatures at the Cut averaged over the period 11.38 to 15.45 BST compared with water temperatures at nearby sites.

	Date	Temperature (°C)		
		Mean	Minimum	Maximum
The Cut	August & September 2020	24.0	20.7	28.0
The Cut	May to August 2021	26.2	23.0	29.0
Comparison sites	Similar periods 2020 & 2021	16.5	14.7	19.4

previous year, which probably accounts for the slightly higher temperatures in 2021 (Table 5). Allen *et al.* (2010) described one of the key habitat features as "low levels of shade…vegetation…of low maximum height". This was certainly the case in August 2020 (Plate 1B), however, by June 2021 there was a rapid growth of rushes (Fam: Juncaceae) (Plate 1C) and other aquatic herbaceous plants at the Cut. In addition, the very local Black Poplar (*Populus nigra*) had been planted along the banks and by August 2021 the Cut had been almost completely overgrown with a range of tall vegetation (Plate 1D), rendering the habitat quite unsuitable for *I. pumilio.* It was quite clear that we were studying a transient and rapidly disappearing population.

But what of permanent populations? Allen & Thompson (2010) carried out Mark-Release-Recapture (MRR) studies at Latchmore in the New Forest and the Red

Plate 10. A male I*schnura pumilio* in copula with a juvenile (‘aurantiaca’) female.

Plate 11. An androchrome female of *Ischnura pumilio* attempting to shake off the attentions of a male while obvipositing. Note the more robust abdomen of the female with eggs.

Plate 12. A gynochrome female *Ischnura pumilio* ovipositing under water.

River Valley, Cornwall. Both sites, although having rather different habitats, are known permanent colonies for *I. pumilio*. The Latchmore population was studied over an eight week period commencing 4 June 2005 and Red River over a four week period commencing 3 June 2006. One of the main conclusions was that, at both sites, *I. pumilio* was "the most sedentary odonate studied in the UK to date." with movements over 150 m very rare (Allen & Thompson, 2010). Is it possible, from the observations made at the Cut, to identify differences between the populations at the permanent habitats (Latchmore and Red River)?

The surveys at Latchmore and Red River (Allen & Thompson 2010) concentrated on population size and dispersal, providing no information on voltinism (generations per year). However, Cham (1993) studied a population of *I. pumilio* in Sundon, Bedfordshire. The main peak occurred at the end of June and the beginning of July, with a gradual tailing off until the end of August.

Sternberg & Buchwald (1999) stated that, in the warm lowland areas of Germany, *I.pumilio* has two emergence peaks, which were observed over several years. One occurred in early June, the other in late August, indicating the presence of a spring generation and an autumn generation; there was no evidence of emergences delayed from spring to summer. In contrast, at higher elevations (>500 m asl), only one emergence peak occurred. In some localities this was in late June/early July, in others from early July through to early August (Sternberg & Buchwald, 1999). The Cut population, particularly in 2020, was very much stronger in August following a steep decline at the end of July. Tenerals and an exuvia were found in early August, implying that there were two generations. In summary, the Sundon colony appears to fit the single generation pattern, whereas the Cut appears to have spring and summer generations.

Water temperature is clearly an important feature for the colony at the Cut. The average mid-day water temperature at the Cut was 50% higher than in surrounding water bodies, probably as a result of the shallow nature of the waters at the Cut, which rarely exceeded 25 cm. The deeper and more shaded parts of the Cut to the north and south are cooler and not favoured by *I. pumilio*. The open, shallow waters of the Cut cool overnight but warm rapidly during the day, allowing for rapid larval development. By way of comparison, large numbers of *I. pumilio* have been observed in rice paddies near Valencia in Spain (DC) where, on 16 September 2017 at 12.23 (BST), the water temperature was 21.4°C. The nearest equivalent time at the Cut was on 1 September 2020 at 12.49 (BST) when the temperature was 21.7°C. Furthermore, not only are the water temperatures at the two sites similar, but the water depths are almost identical.

Perhaps the most striking difference between the permanent colonies and the Cut is the number of female observations: 45% and 36% of the populations at Latchmore and Red River respectively, that were collected for marking were female. In contrast, only 17% of observations were of females at the Cut in 2020, reducing to 7% in 2021. This small percentage recorded at the Cut, and particularly the reduction between 2020 and 2021, suggests that the females are the first to detect habitat changes and are dispersing. In addition, only two immature females were recorded (one in copula) in 2020 and none in 2021. This extremely low number of immatures implies that the females disperse at, or very close to, emergence, which would appear to be a very high risk strategy because the chances of finding both a suitable habitat and a mate would seem very slim. *Ischnura hastata* is a common species along the eastern seaboard of the US. It has thriving colonies in the Azores archipelago, which consist entirely of females. Adolfo Cordero (pers.comm) has individuals taken from the Azores and which have been reproducing parthenogenetically in his laboratory over many generations. Is it possible that this behaviour is not restricted to *I. hastata*

and that other species including *I. pumilio* can reproduce without males?

Grand & Boudot (2006) and Dijkstra *et al.* (2020) both described the androchrome female as rare and Cham *et al.* (2014) provided a photograph of "the first ever andromorph female" in the UK. At the Cut, seven of the 43 (16%) records of females in 2020 were of the androchrome (Plate 8). We have no information about records of the androchrome at the permanent sites, although Paul Winter (pers.com.), who has visited Latchmore on many occasions, confirms that he has never seen it there. Sanchez–Guillen *et al*. (2020) stated that "…individuals that differ in colouration utilize different microhabitats…such as temperature, humidity and background matching." This statement suggests two possibilities:

- Does the androchrome appear from a need to provide a wider range of possibilities for colonising a new habitat? Or
- Does the androchrome appear because of new colonisation factors such as high water temperature?

From the taillight studies, the numbers of males increased in 2021, suggesting that the males are much more loyal to their original breeding habitat than the females. It is possible that the 'taillight' variation is linked to sexual attraction and therefore competition by males to attract females. In the early summer, females are much scarcer. Later in the summer, as female numbers increase, as they did in 2020 (Table 1), the taillight of males appears less complex and is thus perhaps reduced in importance as a sexual attraction.

This paper clearly poses more questions than it answers and it is the hope of the authors that this will stimulate more research into this tiny but enigmatic damselfly.

Acknowledgements

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Perching and roosting postures in adult *Pyrrhosoma nymphula* (Sulzer) (Large Red Damselfly)

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Summary

Although generally considered to be a species that rests with its wings held over its abdomen in a closedwing posture, the author has observed *Pyrrhosoma nymphula* with a diurnal propensity to rest with its wings spread in more half-open wing postures. Furthermore, in contrast to its daytime perching behaviour, late evening observations of roosting *P. nymphula* around a small urban garden pond have consistently revealed that adults habitually adopt 'openwing' roosting postures, either half-open or fully open. Forewings may be pulled forwards up to 110º and may be depressed to approximately 5º above the horizontal plane (Fig. 1); hindwings pulled forwards to between 70º and 130º and depressed by as much as 15º below the horizontal plane. When first settling to roost for the night both sexes may settle with a typically 'closedwing' posture or one of a range of commonly utilised daytime half-open postures. However, a significant number subsequently adjust their position and open their wings to orientations approximately at right angles to the body. There is some evidence that the half-open wing posture orientations are adopted in both males and females earlier in the year, when temperatures are lower; later in the year, as temperatures rise, their behavioural repertoire expands to include more fully open roosting postures. The various hypotheses that have been proposed to explain the significance and function of closedwing versus openwing behaviour are discussed.

Introduction

Most species of damselfly demonstrate a varied range of postures during their diurnal activities, although one posture usually dominates. This is arbitrarily identified simply as either 'openwing' or 'closedwing'. Paulson (2004) defined the former as when the wings are spread at, or close to, a right angle to the abdomen, and held horizontal or slightly above the horizontal plane, whereas closedwing species fold their wings over the abdomen. He discussed possible

reasons for the two types of posture.

Most zygopterans fit into one of these two groups, with the majority classed as closedwing but there are a considerable number of openwing species (Paulson, 2004). There are some species of zygopteran that do not fit into either category, such as *Chromagrion conditum* and *Coenagrion hastulatum*, which usually perch with their wings half-open and held above the horizontal (Paulson, 2004). *Dysphaea dimitiata* (Euphaeidae) is also an exception in that it pulls its wings round beyond 90 degrees, depressing its forewings to 40 degrees and its hind wings to 30 degrees below the horizontal (Paulson, 1981a).

Some of these wing orientations are more predominantly characteristic of a given species (Longfield, 1937; Silsby, 2001; Paulson, 2004); others less so. Furthermore, these postures may be held for longer or shorter periods of time, depending on levels of collective activity or transient changes in the immediate ambient weather conditions (e.g. a cloud passing over the sun (Corbet, *et al*., 1960)). Species of *Lestes* (e.g. *Lestes sponsa*) typically hold characteristic homogeneous openwing postures (and often, more accurately, half-open wing postures).

There is a considerable amount known about the identification, development and habitat requirements of the coenagrionid *Pyrrhosoma nymphula* (e.g., Longfield, 1937; Corbett, 1952, 1962, 1999; Macan & Worthington, 1972; Macan, 1974; Hammond, 1983; Gibbons, 1986; McGeeney, 1986; Askew, 1988; Brooks & Cham, 1997; Mill, 2010). It is an early spring species, beginning its emergence mostly in April or May, depending on whether spring is early or late, and it also emerges later at higher latitudes (Corbet, 1962, 1999). It has a wide range of breeding sites, including ponds, lakes, ditches and canals (e.g. Mill, 2010) and also has a wide range of ecological tolerance (Corbet *et al*., 1960; McGeeney, 1986; Mill, 2010).

A consequence of *Pyrrhosoma nymphula*'s very early emergence is that, during its flight period, the nature of its breeding environment can change dramatically. Plants it favours for settling and roosting in June and July may not have even broken ground in April. Thus *P. nymphula* is a very flexible and adaptable species. Indeed, it has been described by Longfield as being "extraordinarily adaptable" (Corbet *et al*., 1960).

On first emerging and on post-emergent dispersion, *Pyrrhosoma nymphula* adopts the typical closedwing resting posture characteristic of most coenagrionid damselflies. Unlike *Ishnura elegans* and *Coenagrion puella, P. nymphula* generally prefers to disperse away from water and marginal vegetation in order to roost (Corbet *et al*., 1960; d'Aguilar *et a*l., 1986; Silsby, 2001). Information

on its posture is based mainly on diurnal observation and it is classified as closedwing. However, very little is known about its 24-hour activity or the minutiae of its activities. Indeed, little is known of the nocturnal roosting requirements of zygopterans in general.

The aim of this paper is to present observations noted over 30 years of the diurnal perching and nocturnal roosting behaviour of *Pyrrhosoma nymphula* at an artificial urban garden pond.

Material and Methods

This study of roosting and perching behaviour was conducted primarily by observation of teneral and adult *Pyrrhosoma nymphula* over a 30-year period. Night-time roosting was investigated at twilight (dusk and dawn) and after dark with the aid of a torch. In more recent years, digital cameras have allowed greater scrutiny and limit disturbance of roosting insects. Near daily observation took place from 1977 – 1993 and again from 2013 – 2021. From 1994 – 2012 only mid-summer observations were made.

Postures

There appears to be no systematic or coherent definitions of postures adopted by odonates either zygopteran or anisopteran. This makes for some difficulty in categorising or quantifying patterns of behaviour within a species or for cross species comparison.

A number of commonly adopted postures have been identified for *Pyrrhosoma nymphula* (Fig. 1, Plate 1). They are characterised primarily by the angles the fore and hind wings make to the axis of the body as seen from directly above. The angles are rounded to the nearest five degrees. The notation used is Pxx/xx, where the first xx is the angle of the forewings to the axis of the body; the second xx the angle of the hindwings to the axis of the body (Fig. 1).

The various degrees of wing opening between forewing positions 0º (P00/xx) and 5º (P05/xx) are not explored here, but there are clear differences in the airflow and boundary layer effects associated with small degrees of wing openness.

Study Site

The study location is an urban garden (approximately 10 m x 22 m in the Western Park district of the city of Leicester (SK540050). The investigation was carried

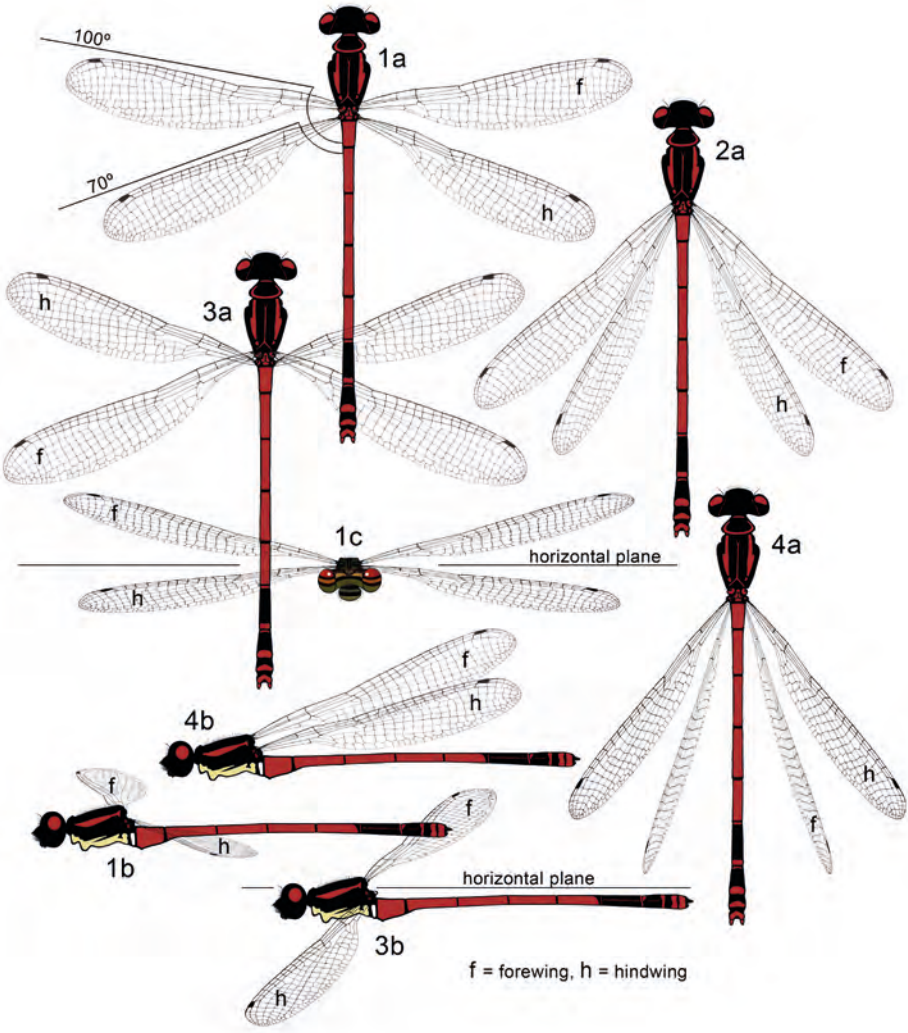

Figure 1. Zygopteran settling postures. 1a (P100/70), 2a (P50/30), 3a (P70/110) & 4a (P20/40) show postures with the wings held open relative to the axis of the body as seen from above; where the first number is the angle of the forewings to the axis of the body; the second number the angle of the hindwings to the axis of the body. 1b, 3b & 4b show matching postures as seen from the side with the wings raised or depressed relative to the horizontal plane; 1c denotes the horizontal plane as seen from head on. In 1a, 1b & 1c the forewings are raised 15º above the horizontal plane and the hindwings are depressed 5º below the horizontal plane. 1a, 1b & 1c correspond with Plate 1H; 3a & 3b with Plate 1J; 4a & 4b with Plate 1D. Note that in 3a and 4a the hindwings are in front of the forewings.

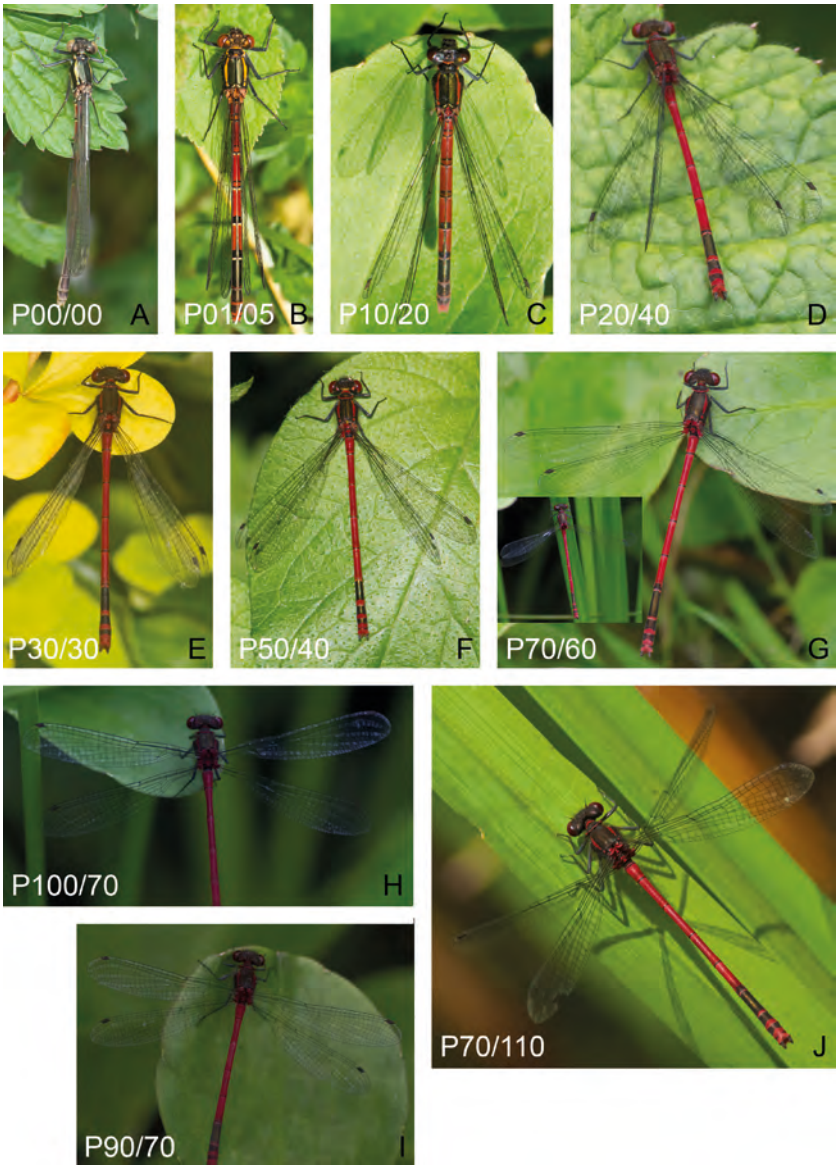

Plate 1. A selection of common, though by no means exhaustive, settling, resting and perching postures used by *Pyrrhosoma nymphula*. (A) a teneral female (form *melanotum*) with the wings fully closed; (B–F) typical diurnal postures; (G–J) resting and roosting postures. In white is a possible methodology to classify the various postures by forewing (first figure) and hindwing (second figure) angles (to the nearest 5º) relative to the axis of the abdomen as viewed from directly above. Position (E, P30/30) marks a transition point, where the forewings move from being held nearer to the body axis than the hindwing (as seen from above), being the more rotated. (J) is an exception to this with the hindwings the more rotated.

out mostly at a small, unshaded, ornamental, wildlife pond approximately 4 m x 3 m. The pond has a winter depth of around 80 cm falling by about 200 mm during dry summer weather. The pond is fed almost exclusively by rainwater, except under exceptional drought conditions.

Observations

In most years, at least 200 *Pyrrhosoma nymphula* emerged from the study pond. However, numbers emerging have varied from year to year. For example, almost 300 emerged in both 2014 and 2018, but only 110 in 2019. Also, the timing of emergence varied. In 2014 the bulk of the emergence was in April; in 2020 emergence was spread over April, May, June and July; whilst in 2021 200 emerged with most of the emergence restricted to the last three days of May and the first three weeks of June.

At emergence, some individuals of *Pyrrhosoma nymphula* remained in the garden but the majority dispersed well away. In less than optimum conditions those that completed their maiden dispersal flight within the boundary of the garden tended to remain there for two or three days, secreting themselves with their wings fully closed, often on the plant where they first settled after their maiden dispersal flight. In the first month of emergence (particularly April) the absence of an abundance of well-grown marginal pond growth and garden plants left little choice for the early cohort other than to disperse; 40 to 50 adults staying close to the pond would raise serious risk of discovery and predation. By June the marginal grass was around 50cm and the iris taller, with flower spikes up to 100 cm.

At lower temperatures, emergents tended to stay put for some time; at warmer temperatures they left sporadically in smaller to larger multiple ‘hops’, usually around six metres per hop (this is commensurate with Corbet’s observations (Corbet, 1962)). At temperatures above 25ºC there was a change in behaviour and, particularly at temperatures approaching 30ºC, some individuals went for an immediate ‘long’ maiden flight, rising almost vertically until out of sight.

Pyrrhosoma nymphula adults returned to the garden pond when mature and ready to breed. They typically arrived in numbers and started to fly over water as soon as the sun was on the pond (earlier on sufficiently mild days). During the day some males were observed to sit with their wings folded along their abdomen, as typical of coenagrionid damselflies, others (the majority on sunny days) with their wings variously spread. The wing positioning appeared to depend on two main factors, weather conditions and the individual’s current activity. On sunny days both males and females spread their wings in an apparently eclectic

spectrum of half-open wing spreading. The range of spreading displayed tended towards either just opening the wings slightly or opening them to about 40º. Many males adopted a degree of spread similar to that seen in some lestids but less pronounced.

On a sunny day, males typically arrived around 9.00 am (BST). Some sunning was sometimes undertaken, though the main activities appeared to be to acquire a transient territory and to have a morning feed. These activities were associated with postures P10/xx, P20/xx and P30/xx. P20/xx and P30/xx were very strongly associated with feeding. In the afore mentioned postures the forewing position has been taken as defining; the hindwing positions are not fixed and may show individual variation for any given forewing position. Males were noted to be strongly territorial both around and away from water. As a consequence of their territoriality, they distributed themselves around the whole of the garden that had been warmed, in roughly equally spaced transient territories which they defended vigorously. Over the ponds this territorial defence behaviour affected the numbers of unattached males, which rarely exceeded about ten on the larger pool and six on a smaller nearby pond. Males mate-guarded the females by forming tandem pairs. These experienced some conspecific harassment but mostly they moved around ovipositing reasonably unmolested.

Males were very pugnacious, leaving their perches to intercept any other odonate entering the immediacy of their mini-territory. Zygopterans challenged in the garden included *Ishnura elegans* (Blue-tailed Damselfly), *Coenagrion puella* (Azure Damselfly), *Lestes sponsa* (Emerald Damselfly) and *Calopterix splendens* (Banded Demoiselle). They also challenged anisopterans, including *Sympetrum striolatum* (Common Darter), which could be ousted when continually harassed from below and behind, and the larger *Aeshna cyanea* (Southern Hawker) but here with little effect. McGeeny (1986) recorded harassment of perched *Leucorrhinia dubia* (White-faced Darter).

Female *Pyrrhosoma nymphula* entering the garden were intercepted by any male whose territory they entered. Males with pond territories did not necessarily do better by being over or immediately around the water as males picked up females from meters away, even the full length of the garden, flying to the water in tandem. Males seemed to have a sufficient understanding of the immediate topography to fly (in tandem) directly and purposefully to the water.

On good days, reproductive activity occurred from around 11.00 BST to about 15.00 BST. On very hot days (the hottest pond-side temperature recorded in 2021 was 41ºC in full sun on 17 July at 13.00 BST) adults withdrew to the shade.

Roosting postures

Even on hot sunny days both males and females started to leave the ponds between 15.00 and 16.00 BST (earlier on days when temperatures reached about 30ºC); although a few males sometimes remained longer. Roosting rarely took place close to water. Most individuals, especially the females, withdrew to roost outside the garden. However, at the height of the breeding season, a small number of mature males (and an even smaller number of females) remained to roost in the marginal vegetation around the ponds.

On suboptimal days when weather deteriorated, e.g., due to cloud cover, *Pyrrhosoma nymphula* settled almost immediately, leaving it potentially grounded with a need to find suitable roosting cover. On sunny days with low ambient temperatures, if the sun was obscured an approximately P70/50 posture was often adopted spontaneously.

At roosting time, individuals moved close to their chosen roost and settled initially with wings variously in half-open positions. This posture was held (or dropped down to a less open posture) whilst the individual stayed suboptimally active. When the final decision to roost had been taken the individual moved to its final resting position and, when satisfied, most individuals then opened their wings more fully. Females typically adopted postures from P20/xx through P100/xx; males more typically from P70/xx through P100/xx (again there can be variation in the exactness of an individual's posture).

Roosting males [Plates 1 (G, H, I & J), 2 & 3] spread their wings often distinctly in a characteristic x-wing position when viewed from above (Plates 2 & 3) and head on (Plate 2C), although there was no singular characteristic body orientation. Tenerals tended to hang vertically. Immatures and adults tended to prefer a more horizontal position on the vegetation, with their bodies held away from the substrate on which they were perching. There was some variation, with a proportion of individuals spreading their wings at an angle greater than 90 degrees [Plates 1(H & I) & 3D].

Without external disturbance (e.g., other insect activity, frogs moving about, rain) the roosting posture and bodily orientation was generally maintained until either sunlight fell on the individual or the ambient temperature rose and it became suboptimally active.

On settling to roost for the evening mature individuals often secreted themselves quite deep inside suitably open bushes. *Pyrrhosoma nymphula* seemed to have no proclivity to repeatedly roost in a favoured spot but chose a new roost each night. There appeared to be a preference for a certain foliage density and

Plate 2. Two males of *Pyrrhosoma nymphula* roosting on Bog Bean. (A, B) a male with the wings pulled forwards (P70/60); (C, D) a male with the wings also pulled forwards (P100/75). The first figure is for the forewings, the second is for the hindwings.

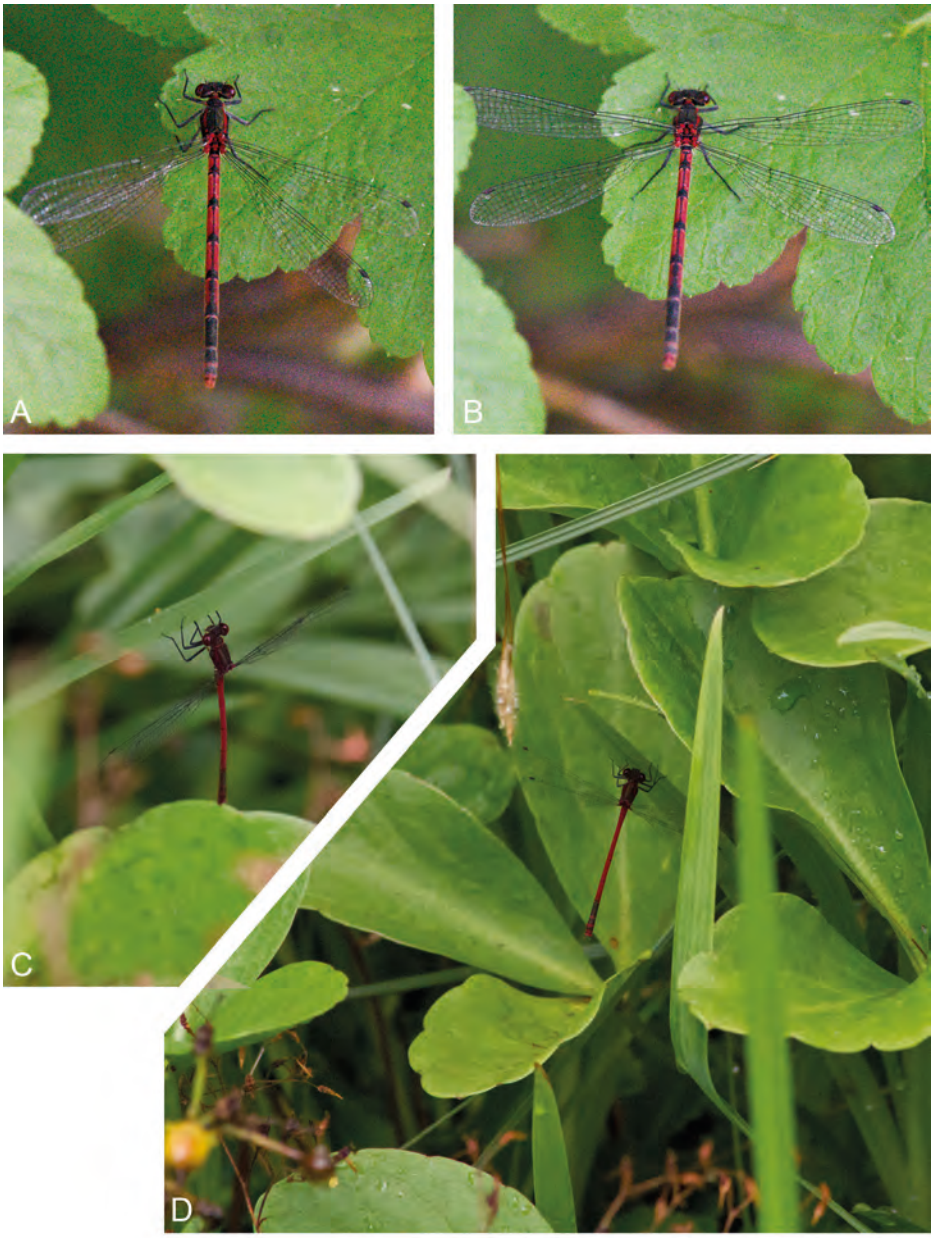

Plate 3. A & B: a female of *Pyrrhosoma nymphula* roosting on 15 June 2021. (In B the posture is similar to that of the male in Plate 2 (C, D)). C & D: a male *P. nymphula* roosting overnight on the 18 July 2020 at 17.59pm BST (C) and, still in position, at 9.49am BST the following morning (D). The degree of foliage cover is typical, with *P. nymphula* tending to orientate facing into the foliage mass.

individuals tended to orientate to face into the mass of the foliage. In contrast, an individual of *Lestes sponsa* was observed to roost on the same three or four *Juncus* stems for nearly a fortnight.

Observations of female roosting in this small garden environment had proven somewhat elusive until 2021. However, the noticeable cold start to 2021, coupled with an unexpected sex imbalance in emergence, left the pond populated almost entirely with females. The cold further suppressed the normal dispersal of this early cohort. Thus, a number of females remained around the pond in late April (daytime temperatures in the range of 10ºC to 16ºC; night-time –1ºC to 4ºC) and roosted in whatever cover was available. In April they roosted in ivy and under a conifer and adopted postures in the range P20/20 to P50/50 (sometimes to P70/xx) with the hindwings appearing to be depressed below the horizontal and the abdomen held at around 45 degrees away from any substrate. Individuals settled at around 16.30 BST and remained settled until around 12.00 BST the following day on days when activity was not suppressed.

In early May, similar postures continued to be held, around P40/40, when daytime temperatures were in the range of 9ºC to 14ºC and night-time 1ºC to 6ºC. In early June, males started to adopt P70/40 to P100/70 postures with forewings raised between about 5º and 15º above the horizontal plane and hindwings depressed by about –5º.

Later in the year (15 June 2021), a female was seen to adopt similar postures to the males (Plate 3 A, B), with wings opened to around P70/50 (Plate 3A), settling at 20.39 BST and adjusting variously over night to P100/70 at 06.49 BST. The P80/70 posture, with wings raised, was held through 07.30 to 08.06 BST before becoming active. Daytime temperatures around the pond (marginal vegetation) reached 32ºC in full sun and 25ºC in shade from midday to early afternoon; with early evening still around 30ºC in full sun and 20ºC in shade.

To illustrate typical behaviour, a male *P. nymphula* roosting in typical foliage is described for the night of 18/19 July 2020. The male made two roosting attempts before settling into position at 17.59 BST (Plate 3C). In each case it adopted the same posture but presumably, not fully satisfied with its chosen position on its first two attempts, it ‘powered up’ (wing whirring whilst holding tightly onto its substrate) and moved a few inches further into the herbage before finally settling for the night. It was still in the same position at 09.49 the following day (Plate 3D). Soon after this it changed position and closed its wings prior to eventually taking off in an initial daytime flight.

Discussion

It is generally held that a significant difference between zygopterans and anisopterans is how they hold their wings at rest. Anisopterans typically extend their wings fully to about 90º to the axis of the body (openwing). In aeshnids the wings are usually all in the same plane: libellulids often have their wings slightly raised or dropped. Most zygopterans usually perch with their wings closed in the vertical over their abdomens (closedwing), especially when immature. However, most members of the Lestidae, Synlestidae and Megapodagrionidae perch with open wings (Silsby, 2001). In other zygopteran families, some species occasionally perch with open wings (Corbet, 1999; Paulson, 2004). Paulson recognised that the division into openwing and closedwing is not comprehensive, with some zygopterans alternating open and closed positions; and some in the family Coenagrionidae including *Chromagrion conditum* and *Coenagrion hastulatum*, habitually perching with the wings approximately half-open, well above the horizontal plane.

Paulson (2004) discussed a number of hypotheses in the context of his definition of an openwinged species: 'Phylogenetic Inertia' (Heymer, 1975), 'Wing Display' (Heymer, 1975; Paulson, 1981a, b) and 'Theremoregulation' (Jacobs, 1955; Corbet, 1999). He concluded that none of these explained all of the data. He proposed two further hypotheses: 'Quick Takeoff' and 'Shiny Wing' (Paulson, 2004). The idea of the Quick Takeoff hypothesis is that openwing species take flying prey, but so do many closed winged species; also, an explanation is needed as to why most zygopterans are closedwing species. He concluded that the Shiny Wing Hypothesis explained the data better. This suggests that openwing species are more likely to be predated because they are more conspicuous and species that perch in shade are less conspicuous than those that perch in the open. Larger species (most anisopterans) are at a lower risk of being predated and most of the openwing zygopteran species are large, shade-loving species (Paulson, 2004).

Though not scientifically rigorous a quick trawl of images posted on the internet (on the 19th August 2021) showed that a number of zygopterans perch with half-open wings at least some of the time. The percentages of openwing relative to closedwing, excluding pairs and tenerals, were *Chromagrion conditum* 81%, *Coenagrion hastulatum* 33%, *C. lunulatum* 31%, *C. pulchelum* 27%, *C. puella* 25%, *C. ornatum* 23%, *C. scitilum* 11% and *C. hylas* 19%. The value for *Pyrrhosoma nymphula* was 62%. For comparison a member of the Lestidae (*Lestes sponsa*), often described as either openwinged or half-open winged, had a value of 93% openwing relative to closedwing.

Perching at night revealed similar variation in wing positioning. Corbet (1999)

recorded researcher's observations of the behaviour in a number of species, which roost with half-open wings. These included *Mnais pruinosa costalis* (Aria, 1994, cited by Corbet 1999), a number of European species of C*alopteryx* (Zahner, 1960) and C*alopteryx splendens* (Paine, 1994, 1995). Neubauer & Rehfeldt (1995) noted that this half-open wing position was typical only for the period of darkness in *Calopteryx haemorrhoidalis*; normal closed-wing roosting positions were adopted prior to the time when the sun was up.

The author observed *Pyrrhosoma nymphula* closed its wings if/when bathed in sunlight, including temporary wing closure after roosting, should stray or late sunlight shafts pass over the roosted individual. As light levels fell their previous open winged posture was resumed. That *P. nymphula* roosts with wing postures P70/xx through P100/xx and hindwings depressed below the horizontal would seem to make it a possible candidate for openwing status.

Again a quick trawl of images posted on the internet (on the 19 August 2021) of the wing spread of *Chromagrion conditum* as (*Pyrrhosoma nymphula's* closest relative (Zhaoying *et al*., 2013)) matched those of the author's photographs of *P. nymphula (*Plate 1), illustrating wing positions up to P40/xx, though with a higher bias toward P50/xx postures*.* Images of *Dysphaea dimidiata* on the internet revealed quite clearly its proclivity for bringing its wings well forward and down, but *D. dimidiata* also has other eccentricities; the male's wings are large, very broad along their length and highly coloured. Showing off its spectacular and very variably patterned wings would seem of importance to the species.

Choice of a suitable habitat for night roosting may be essential in terms of thermoregulation, saving energy and protection against unfavourable conditions and predators (Hykel *et al*., 2017). Tracey *et al.* (1979) concluded that when the odonate body was horizontal to the substrate, with its thorax raised off the substrate and its wings held straight out parallel to the substrate, there was a thermal advantage.

An odonate's temperature can benefit from the influence of thermal radiation from the warm substrate beneath its body. Such a temperature difference can be substantial. Hilfert (1995) noted during observations, albeit on odonate early morning behaviour, that *Ischnura elegans*, by perching on a substrate such as a grass stem, was able to take advantage of a temperature of 8.4^0C greater than the ambient temperature and warm its body endothermically. Neubauer & Rehfeldt (1995) proposed that open-winged nocturnal positioning could reduce substrate cooling during the night. This in turn would speed up gaining ectothermic temperature increase during the morning. Hence nocturnal wing spreading behaviour in *P. nymphula* may be reflective of a response to these thermal aspects.

It is possible that the male observed to take three attempts to settle (Plate 3 C & D) may not have been maintaining a sufficient body temperature on the vegetation at the pond edge, possibly potentially signified by its behaviour prior to finally settling, the individual having made two roosting attempts before remaining at the site as photographed. In each instance the individual underwent wing whirring prior to moving. Wing whirring is known to provide a means of endothermic body warming prior to flight (May,1991), suggesting that the vegetation at this location may have been perceived to be inappropriate for final roosting, because either it was too cold or there was too little foliage cover; other damselflys show a proclivity for a particular foliage density around them when settling (pers. obs.).

It is not so clear as to the above thermal advantages of openwing positioning in April when night-time temperatures may drop below zero. In 2021 those *Pyrrhosoma nymphula* individuals roosting in April spent some 18 hours plus 'roosted' or grounded due to low daytime temperatures and roosted with night-time temperatures falling to 1ºC and 2ºC with one night (28 April) given as expected to fall below zero (Met Office, 2021).

There seems to be no available information as to whether small zygopterans gain any thermoregulatory advantage by closing their wings tightly together or tightly against the abdomen and settling down onto a suitable substrate, thereby trapping insulating layers of air between the wings and/or the abdomen and/or the substrate.

Whatever the driving forces are that have shaped the settling and roosting preferences of *P. nymphula*, it has had to develop a broad repertoire. The species requires a strategy that works both in early spring when daytime activity may be limited to no more than two or three hours with little cover to the much warmer conditions in midsummer.

In conclusion, this paper presents observations confirmed over 30 years on the night-time roosting behaviour of *P. nymphula*, mostly males. The openwing nocturnal roosting postures do not appear to have been formerly recorded previously in *P. nymphula* and may possibly reflect a readiness for activity on disturbance or a thermoregulatory behaviour or an interplay of both. It is hoped that these observations go some way to contributing to future study in this area, particularly of raising the issue of the thermal requirements for night roosting sites in this species.

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