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The aims of the **British Dragonfly Society** (BDS) are to promote and encourage the study and conservation of Odonata and their natural habitats, especially in the United Kingdom, and to raise public awareness of dragonflies.

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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Management of breeding pools for *Aeshna caerulea* (Azure Hawker) and *Leucorrhinia dubia* (White-faced Darter) on the Corrour Estate, Inverness-shire, in North-West Scotland.

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Summary

Corrour Estate, is a remote Highland estate on the eastern edge of Rannoch Moor, Scotland and an important site for *Aeshna caerulea* (Azure Hawker) which breeds there in shallow bog pools. Surveys have shown that larvae are very vulnerable during extended periods of dry weather due to their breeding pools drying out.

The British Dragonfly Society, supported by the Corrour Estate, initiated trial management to restore and create pools with deeper refuge areas to aid larval survival. Deeper pools also proved to be suitable habitat for another rare species, *Leuchorrhinia dubia* (White-faced Darter). Nine other breeding odonata species at Corrour were also found to benefit from this work. The results of the trial will be used as an aid to inform further management at Corrour and in other areas across Scotland towards the conservation of these rare bog species and dragonflies in general, and to ameliorate the challenges of ongoing climate change.

Introduction

Aeshna caerulea (Azure Hawker) is a relatively small, blue and black hawker dragonfly. The males are bright blue and the females occur in two forms, a brown and a blue form. It has a highly restricted distribution in Britain, being confined to just five areas of the Scottish Highlands (Cham *et al.*, 2014). The species is classed as Vulnerable on the British IUCN Red List (Daguet *et al*., 2008) and of high conservation priority. It is now Near Threatened under a recent European assessment (De Knijf *et al*., 2024).

One key area where *A. caerulea* breeds is Corrour. This is a large, remote estate located at the eastern edge of Rannoch Moor, Inverness-Shire (NN36). The estate comprises 23,000 hectares (230 km^2) of high-level ground with an altitude mainly above 300 m above mean sea level (amsl), including 5,750 hectares over 600 m amsl. Blanket bog, containing numerous lochans and bog pools, covering 7,043 hectares (Corrour, 2020).

Rare and threatened Odonata at Corrour

Aeshna caerulea (**Azure Hawker)** *Aeshna caerulea* was first recorded at Corrour by P.H. Grimshaw in 1914 (NBN Atlas, 2024). Since 1997 there have been scattered breeding records from a limited number of pools across the estate. In 2019 a detailed larval survey of known Scottish sites, including Corrour, was carried out (Batty, 2019).

Larvae of *A. caerulea* can be found in small shallow bog pools with a depth of 10-30 cm with floating Sph*agnum cuspidatum* (Feathery Bog-Moss*)* and *Eriophorum angustifolium* (Cotton grass) (Smith *et al*., 2000; Clarke, 2002; Willet, 2013; Batty, 2019). These pools can be as small as 1 m x 2 m, or long narrow pools up to 20 m long and 1 m wide (Plate 1). The larger pools often have islands in the middle. During particularly dry periods the deeper pools, with a depth of 40-50 cm, are utilised by larvae.

Larvae of *A. caerulea* take three to four years to develop (Smith *et al.*, 2000; Clarke, 2002). The final instar larvae measure 34-39 mm (Cham, 2007). They are often found in pool complexes, but do not appear to use the same individual pools every year. In September 2019 a survey recorded 231 larvae in 16 pools. One hundred and thirty-nine (62%) of these were from nine pools in the area close to Corrour railway station. This represents the greatest number of larvae recorded from any Scottish site in recent years, highlighting the importance of the Corrour Estate for the conservation of this species.

Under certain conditions many of the small early instar larvae (10-19 mm) are unlikely to develop to the final instar. During 2020 and 2021 there were extended periods of dry weather and the majority of breeding pools were either dry or in poor condition (Plates 2 & 3). Small larvae would have difficulty moving any distance to deeper pools. In September 2021 only three larvae were found in only two of the deeper pools. A more extensive survey in spring 2022 produced similar results. Over 120 pools were sampled, with nine larvae found in four pools; two of the pools were the same as in the previous autumn.

Other areas with breeding populations of *A. caerulea* also experienced similar dry conditions during this period. This has implications for the long-term survival of the species in Scotland, particularly as the duration and frequency of droughts

Plate 1. A long narrow pool in Corrour Station area in September 2019 showing typical breeding habitat for *Ashna caerulea*.

is expected to increase as a result of ongoing climate change (NatureScot, 2020). The species is already feared to be extinct in its most southerly British site in south-west Scotland, (Clarke, 2021).

***Leucorrhinia dubia* (White-faced darter**) *Leucorrhinia dubia*, in very small numbers, has also been confirmed as a breeding species on the Corrour Estate. This species is a rare bog specialist and classed as Endangered in the British Red List (Daguet *et al*., 2008). It was first recorded at Corrour in 2021 when a handful of larvae were found in just two pools. Larvae prefer deeper pools than *A. caerulea*, with a depth of >30 cm, where open water and floating *Sphagnum* is present (Cham *et al.*, 2014). In Scotland larvae take 2 years to develop and the ones found at Corrour measured 10-15 mm. The final instar was 18-22 mm long on average (Cham, 2007). *Leucorrhinia dubia* could have been present at Corrour for some time but gone unnoticed due to its very small population.

Plate 2. An example of Corrour Station area pools which were drying out and infilling in September 2021. The whole Sphagnum area in the picture was originally filled with water.

Plate 3. A completely dry small pool in the Corrour Station area in September 2021.

Methods

Trial management strategy at Corrour

Due to climate predictions and the threats from drought, a plan of action was developed in order to strengthen the population and ensure the long-term survival of *Aeshna caerulea* and *Leucorrhinia. dubia* on the Corrour Estate. The British Dragonfly Society (BDS), with the support of Corrour Estate management staff, carried out trials to create and manage a number of pools of varying sizes with deeper refuge areas of 80 cm to over 1 m deep and at least 1 m^2 in area. These pools were located in the two main known breeding areas for *A. caerulea* at an altitude of over 400 m amsl. These higher altitude sites were considered to be more likely to ameliorate the effects of climate change. It has been noted that natural pools with deeper retreats at Forsinard in the Flow Country blanket bog of East Sutherland enabled the survival of larvae of *A. caerulea* during dry conditions (Smith *et al.*, 2000).

The first area for pool creation was 700-800 m north-east of Corrour Station NN356667. The second was near the track to Lubnaclach ruin NN375651, 3.5 km to the south-east of the station area (Figs.1 & 2). Pools of different sizes and depths were created to encompass the habitat conditions required by *A. caerulea* and *L. dubia*. These included a design which has been successfully used for a reintroduction of *L. dubia* in Cumbria (Clarke, pers. comm.). Work was carried out sympathetically to avoid adversely affecting existing breeding pools. The management work at both sites was aimed at minimal intervention. It mainly comprised a restoration of existing pools by using the topography and strategically placed dams. Only a limited number of completely new pools were made as part of the process. The work consisted of:

- Inserting small peat dams at strategic points to raise the water level and reduce drainage.
- Digging out small sections where shallow areas had dried out. Small pools sized 1x 3 m and 0.7-1.0 m deep were also formed when excavating the peat for dams.
- This work created a number of pools of various sizes and depths, including small pools 2 x 4 m and long sinuous pools, 1- 2 m wide with shallow areas and deeper refuges and depths varying from 0.4 m to 1 m. (A larger, deeper pool specifically for *L. dubia*, 40 m^2 with straight sides and 1.5 to 2 m deep at the edge, was also included).
- Carefully removing and transferring some *Sphagnum.* The *Sphagnum* was gently scooped up using a digger bucket, placed in a nearby pool and then returned to the water collecting in the newly dug area.
- The spoil was used for creating dams in the eroding peat channels

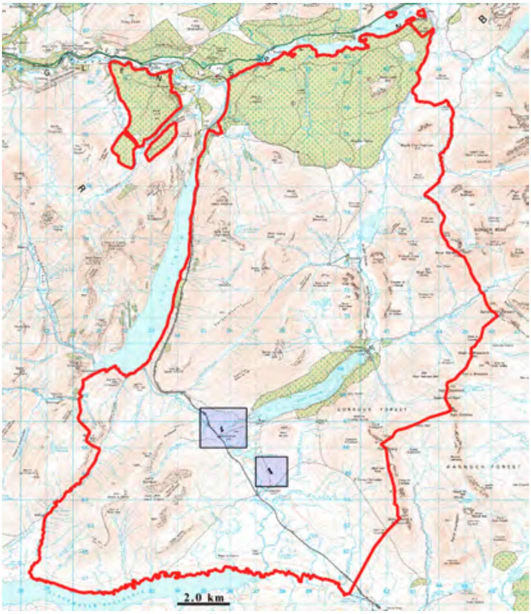

Figure 1. The extent of Corrour Estate, Inverness-shire, and the trial management areas The black boxes show the two trial areas. Red outline, Corrour Estate boundary. Map by kind permission of Corrour Estate. (© Ordinance Survey).

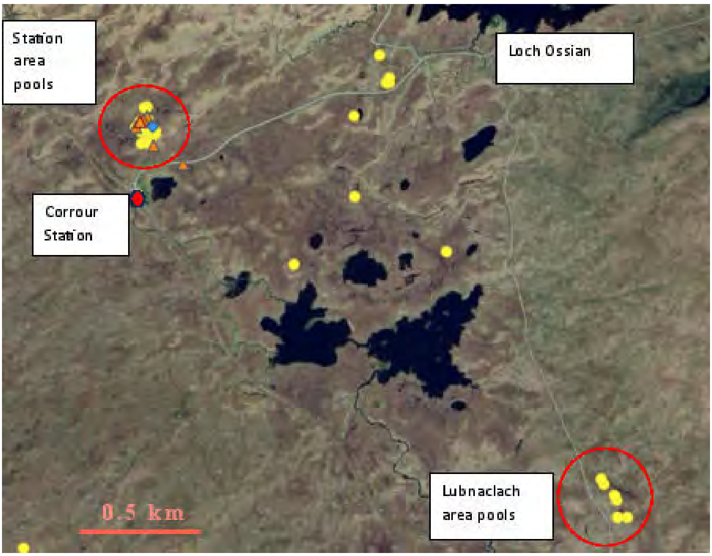

Figure 2. The location of the two trial management sites (red circles) (Station area and Lubnaclach area). Blue diamond, *Somatochlora arctica* breeding site; orange triangles, Leucorrhinia dubia breeding pools; red dot, Corrour Station; yellow dots, *Aeshna caerulea* breeding pools. (© Ordinance Survey).

in the vicinity. It was also used to create moraine-like hummocks or sheltering bunds, by first carefully removing the vegetation layer, then replacing it on the new mound to avoid peat exposure.

On 23-24 March 2023 14 pools were dug or modified. These encompassed a range of shapes and sizes (Tables 1 (Corrour Station area) & 2 (Lubnaclach)). Work was carried out by contractor Norman Campbell, using a small tracked excavator. In addition to the 14 main pools, there were two very small pools 1 x 2 m and 1 m deep, created when excavating peat for the dam, which were located at a lower level. These did not retain water consistently and so have not been included in the total number of pools assessed.

The Lubnaclach L1 complex had 20 larvae of *A. caerulea* in 2019 and was the only studied site that had retained larvae. Two were found in 2022, although the site was in poor condition, so it was decided to install four dams to raise the water table of the complex.

All 14 pools were sampled for larvae in May and September 2023 and September/October 2024. A colander or net was used and all larvae found were returned unharmed to the pools. At least 30 minutes was spent at each pool and, where possible, all the edge habitat was sampled. For the larger pools, sampling areas were chosen. The body lengths of the larvae of *A. caerulea* and *L. dubia* were recorded.

Data arer also provided based on the larval survey of *A. caerulea* in 2019 (Batty, 2019) and of the Corrour site in 2022 (Batty, unpub.).

Results and Discussion

Following their creation, the pools started to fill and, by May 2023, all the pools were full and noticeably had more water than the surrounding pools. Those surrounding pools had started to dry up and were markedly infilling with *Sphagnum* after a period of prolonged dry weather. The dams at Complex L1 (Lubnaclach) had raised the water table considerably, creating an extensive wetland area (Plate 4). Only site L6 at Lubnaclach had limited areas of open water. In areas partly infilled with *Sphagnum* the water was over 30 cm deep.

Aeshna caerulea

Remarkably, by May 2023, only two months after the management work, nine *Aeshna caerulea* larvae were present in six of the 14 pools, with cast larval exuviae also found. These were mainly in pools that had been extended

Table 1. Trial Management pool details in the Station Area of Corrour.

Pool Number	Grid ref (all NN)	Measurements	Depth	Other information
St1. Dammed U- shaped pool	3570966618	u-shaped pool 16x10 m	1.5 m deep at new dam	Also deepened at both sides at bottom of u-shape.
St2. Deepened pool and dammed complex	35676671	Pool 7x6 m	Various up to 1 m deep	The edge of pool complex was dug out and inter-connected runnels left to create a pool with varied habitats and a deep area of >1m. The runnel was dammed but water continued to flow to the area below. Material dug out created a sheltering moraine like mound.
St3. Dammed shallow pool previously dry	3567866771	Pool 3.5x2.5 m	70 cm deep	Deepened shallow pool that had previously dried out. The pool was also linked to other infilling pools by a S*phagnum cuspidatum* filled channel. The limited outflow was dammed excavating a very small pooL1 X 2m below.
St4. New deep pool (for *L. dubia*)	3570066749	New pool 4x4 m	>1.0 m deep	Created specifically for *L. dubia* with two steep sides, in deep peat.
St5. Dammed pool complex	3572166663	10x4 m	1.0 m deep	Dug out shallow pool in complex & the outflow dammed to raise water level. The pool had a peaty substrate and was linked to other drying pools with a sphagnum filled runnel.
St6a. A long shallow pool dug out and a dam inserted	3571066667	9 x1 m	0.5 m	Dug out long, narrow, shallow pool.
St6b. Frog Pool, New pool	3571266667	3 x 4 m	0.7 - 1.0 m	Frog pool. A pool created when excavating peat for the adjacent dam and pool.

Table 2. Trial Management pool details in the Lubnaclach Area of Corrour Estate..

Number	Grid ref (all NN)	Measurements	Depth	Other information
L1.Complex Dam a Dam b Dam c Dam d	 3749365151 3749165175 3751065180 3752465169	Very large complex covering 70-80 m with 7 arms of different widths (5 -15 m)	Varies from 0.3 m to 2 m in the central area, 40-50 cm deep at edge	Four dams were inserted Dam a in the SW area with the smallest outflow Dam b at the N end of complex Dam c at the NE side of complex, having the biggest outflow. Dam d is the most easterly before water descends into an eroded peat area.
L2. Small pool 2	3750065144	PooL5 x 5 m Arm 6 x 1 m	0.4 m 0.4 m	A small drying pool was dug deeper & and the material used to create dam a nearby; a shallow arm was untouched.
L3. Pine pool	3754965101	6m x 4 m	Depth 0.5 to 1.5 m	An existing shallow pool was dug deeper and a buried pine root excavated. Pool is oval with 1.5m shelf at south side. The *Sphagnum cuspidatum* from the filled depression to the east was carefully added to the pool.
L4. Long pool 1	3755665086	10 x 1 to 1.5 m	0.4 m	A long narrow pool was scooped out and dammed at the south end. The E section kept shallow.
L5a. Kidney pool 5b. Long pool 2	3755965036	3 x 2 m 40 x 1 m	0.5 m 0.4-1.0 m	A kidney pool was dug out to create a dam on an existing shallow long pool. Two pools were created.
L6. Lower large pool complex	3758465009	2 to 5 m x 45-50 m	Various depths in different area > 30 cm.	The outflow was dammed to retain a large pool complex with sinuous pools many of which were infilling with *Sphagnum*, A small pool was created in the process at a lower level below the dam but did not consistently retain water.

Plate 4. Lubnaclach L1 pool in May 2023. This is a large wetland complex. *A. caerulea* breeds in the shallower water in the inlets. Larvae were found at this site on every visit throughout the study.

Plate 5. Station pool St6b (frog pool) in September 2023. This is a new, small deep pool where later instar *A caerulea* larvae were found in September 2023 and September 2024. It is likely they travelled overland 18m or more.

and deepened, although they could have been introduced with transferred *Sphagnum* (Tables, 3 & 4).

After only six months (i.e. by September 2023), *A. caerulea* had been found in eight of the 14 pools (57%) in total and the number of larvae had increased to 14. The additional pool was the small 'Frog pool' St6b (Plate 5). This was a new pool and had not been seeded with *Sphagnum*. Two *A. caerulea* larvae 34 mm long were found here in 2023. They were final instar larvae and could not have developed in six months. They had probably travelled overland, which has not been known before. The nearest pools were over 18m away and were drying out. A further two larvae 27mm and 37mm long were found in this pool in September 2024.

However, in September 2024 there was an overall decrease in larval numbers and pools occupied by *A. caerulea*. Only eight larvae were found in five pools (Tables 3 & 4). Some reduction in larval numbers was to be expected as some would have emerged earlier in the same year. Winter mortality of larvae is regarded to be low (Smith *et al.*, 2000), possibly due to reduced activity by predators during colder conditions.

Size range of larvae

Of great significance for *A. caerulea* was the size of the larvae, with 70% 30 mm or over thus reaching their later instars and therefore more likely to reach adulthood. In fact, this was the largest number of large larvae found at any site post 2000.

From other survey work there was generally an abundance of smaller larvae and very few larger larvae that had reached their final instars. In the 2019 survey at Corrour this was the case (Fig. 3).

Larvae take three to four years to develop to adults (Clarke, 1994; Smith *et al*., 2000). It is cited that eggs laid in June/July enter diapause and then hatch the following spring (Corbet & Brooks, 2008). Larvae under 10mm are likely to be under-represented as when a colander is used in detritus-filled pools the very small larvae are not caught. They grow to 8-11 mm in the first year before over-wintering (Smith *et al.*, 2000). Development can then progress for a further two to three years with emergence in year five (Clarke, 1994) (Plates 6 & 7).

From the data collected in 2019, the peaks (Fig. 3) appear to show three approximate age cohorts of annual development at Corrour. Growth rates can vary between sites and pools dependent on the conditions and food availability (Smith *et al.,* 2000). During captive rearing, larger larvae in their 2nd and 3rd year

Table 3. Results of the survey work for 2023 and 2024 from the Station Area pools.

Pool Number	**29-31 May 2023 *A. caerulea* larvae**	**14 Sept 2023 *A. caerulea* larvae**	**6 Sept 2024 *A. caerulea* & L. dubia larvae**	**Other odonata 2023 & 2024 Larvae unless otherwise stated**
St1. Dammed U- shaped pool	No Possible adult	1 at 38 mm	***L. dubia*** 1 10 mm	*Libellula quadrimaculata*, *Aeshna juncea*, *Pyrrhosoma nymphula*, *Ischnura elegans*,E*nallagma cyathigerum.* *Sympetrum danae* (adult)
St2. Deepened pool and dammed complex	1 at 18 mm in sphagnum	1 at 29 mm + 2 cast skins	***L. dubia*** 10 7 at 10 mm 2 at 13 mm 1 at 14 mm ***A. caerulea*** 1 38 mm	*L. quadrimaculata,* A. *juncea*, *P. nymphula*, *Lestes sponsa* *E. cyathigerum* (adult, ovipositing) *S. danae* (adult)
St3. Dammed shallow pool previously dry	2 at 17-18 mm	1 at 19 mm	***A.caerulea*** 1 at 36 mm	*L. quadrimaculata*, *A. juncea*, 2 with legs eaten. 3a pool for dam *P. nymphula*.
St4. New deep pool for *L dubia*	No	No	No	No Translocated *Sphagnum cuspidatum* in Sept. 2024.
St5. Dammed pool complex	No	No	No	*L. quadrimaculata*, *P. nymphula A.juncea* (adult) Translocated sphagnum in Sept. 2024 .
St6a. A long shallow pool dug out and a dam inserted	No	No	No ***A. caerulea* 5** 3 at 10 mm 1 at 14 mm 1 at 15 mm (transferred from pools below)	*L. quadrimaculata*, *P. nymphula*
St6b. Frog Pool, a new pool	No	2 both at 34 mm	***A. caerulea*** 2 1 at 37 mm 1 at 27 mm + 6 cast larval exuviae	*L. quadrimaculata*, *P. nymphula*.
Total Station area pools	***3* in 2 pools**	**5 in 4 pools**	***A. caerulea 4* in 3 pools** ***L. dubia* 11 in 2 pools**	

Table 4. Results of survey work for 2023 and 2024 from the Lubnaclach Area pools. The combined results for both the Station and the Lubnaclach Area pools are shown in red in the bottom row.

Pool Number	**29-31 May *A. caerulea* larvae**	**14 Sept *A. caerulea* larvae**	**29 Oct 2024 *A. caerulea* & L. dubia larvae**	**Other Dragonflies 2023 & 2024 Larvae unless otherwise stated**
L1.Complex Dam a Dam b Dam c Dam d	I cast skin	4 1 at 24 mm, 1 at 34 mm 2 at 35 mm	***A. caerulea*** **1** at 35 mm *Sphagnum* by dam b	*Aeshna juncea*, *Libellula quadrimaculata*, P*yrrhosoma.nymphula* *Sympetrum danae* (adult).
L2. Small pool 2	No	No	Good *A. caerulea* habitat developing	*A. juncea*, *L. quadrimaculata*, *P. nymphula*
L3. Pine pool	4 at 18.20,22,28 mm (in at least 2nd year). In *Sphagnum* tucked in the edge	2 both 36 mm	No - some suitable habitat	*L. quadrimaculata*, *P. nymphula*.
L4. Long pool	1 at 30 mm in *Sphagnum* by dam (wing buds just on segment 3)	No	No - good areas of *Sphagnum*	*A. juncea*, *L. quadrimaculata*, *P. nymphula*.
L5a. Kidney pool 5b. Long pool 2	No	No	No	5a *L. quadrimaculata*, *P. nymphula* 5b *A. juncea*, *L. quadrimaculata*, *P. nymphula*.
L6. Lower large pool complex	1 at 22 mm in dense *Sphagnum*	3 la 16 mm,19 mm and 35 mm	***A. caerulea*** **3** 1 at 8 mm 1 at 9 mm 1 at 11mm	*A. juncea*, *L. quadrimaculata*. (*L. quadrimaculata* in small pool that had dried out earlier).
Total Lubnaclach	***6*** **+ 1 cast larval exuvia in 4 pools**	**9 in 3 pools**	***A. caerulea*** **4 in 2 pools**	
Total all 14 pools	**9 in 6 main pools**	**14 in 7 pools**	**Sept/Oct 2024** ***A. caerulea*** **8 in 5 pools** ***L. dubia*, 11 in 2 pools**	

Plate 6. *Aeshna caerulea* larva showing the mid-dorsal pattern. Photograph by David Clarke.

Plate 7. *Aeshna caerulea* larva 37mm long showing the characteristic narrow labium. Photograph by Graham Rennie.

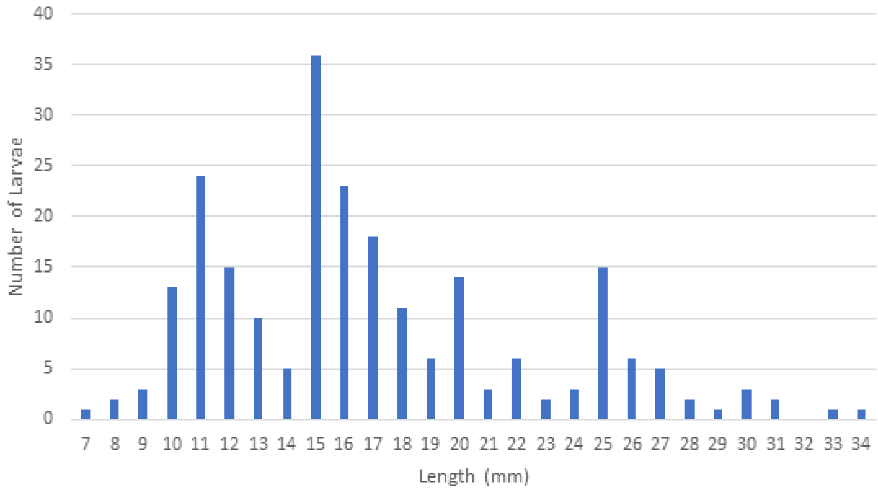

Figure 3. The length of *Aeshna caerulea* larvae at Corrour Estate. 19-20 September 2019, n=231.

also showed a spread of sizes due to growth at different rates (Clarke,1994).

However, it is worth noting the lack of large larvae 30mm or over in 2019; only seven, 3% of the total. The majority (70%) were between 10-19mm, 25% were 20-29mm and 2% less than 10mm (Figs 3 & 4). This reflects findings elsewhere (Batty, 2019, Willet, 2013) where final instar larvae were only 1% of the total; in fact only one larva of this size was recorded in studies at the two other sites.

For all dragonfly species, the number of early instar larvae is significantly higher than the final instar larvae as mortality occurs at all stages of development. This is likely to be more so for *A. caerulea* whose development takes a number of years. However, the level of survey effort indicated that *A. caerulea* has a high mortality rate (Batty, 2019).

However, in the trial pools, using data from September 2023 and October 2024, 59% (13 of the 22) of the larvae were ≥ 30mm (Fig. 5). These were all 34mm or above and in their final instar. In contrast, in 2019 only one larva was that size (Fig. 3). Final instar *A. caerulea* larvae are 34-39mm just prior to emergence (Smith *et al.*, 2000; Willet, 2013).

Comparing larval sizes in the trial pools between May and September 2023 (Fig. 6) some pools had more large larvae than would be expected after six months growth. This could be explained by final or late instar larvae moving 20 m or more into managed pools as the surrounding habitat dried, a highly

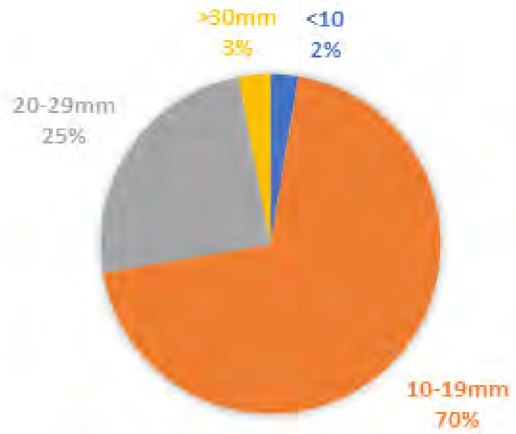

Figure 4. The size distribution of *Aeshna caerulea* larvae found in the pools sampled on Corrour Estate. 19-20 September 2019, n=231.

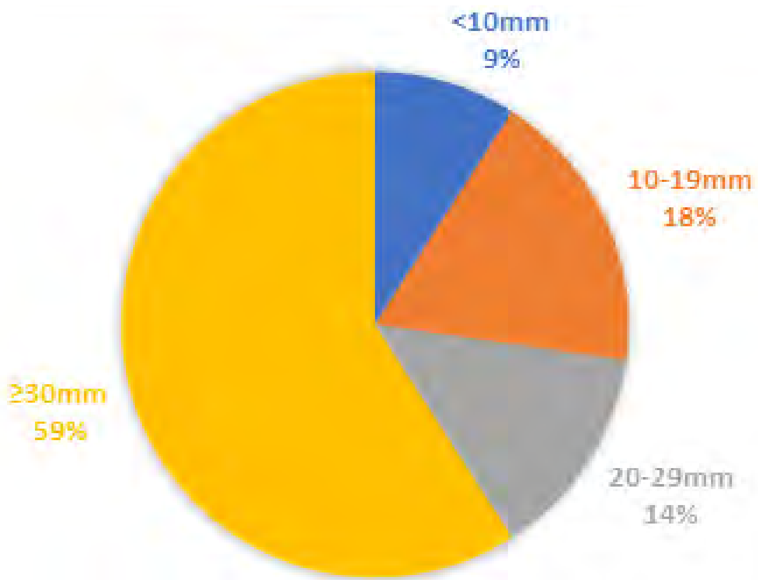

Figure 5. The size distribution of *Aeshna caerulea* larvae found in the trial pools at Corrour Estate. September 2023 & October 2024, n=22. (Only the data for the autumn months at the end of the annual growth period is included).

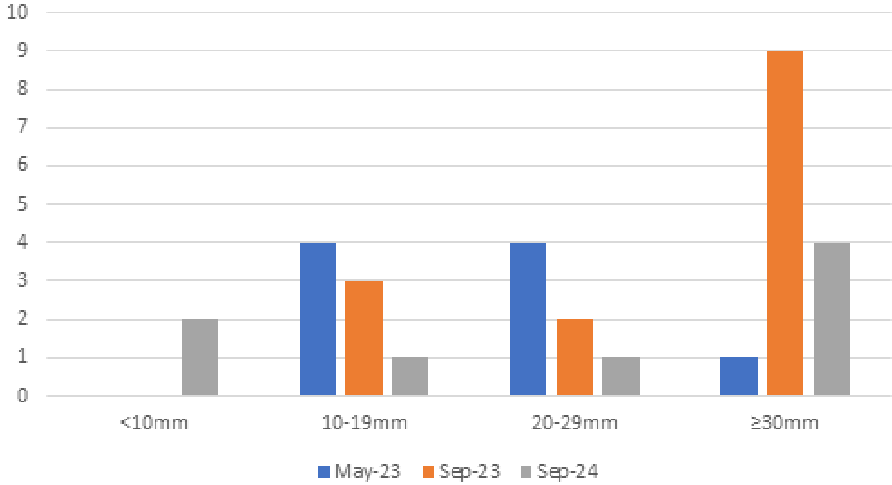

Figure 6. The larval size range of *Aeshna caerulea* in the trial pools at Corrour Estate. May 2023 to September 2024, n=31.

dangerous strategy. From the topography this was possible at pools St2 & St3 (Plate 8) (and also at the L3 Pine pool at Lubnaclach).

There remains the possibility that there was immigration of larvae into the Frog pool (ST6b) in 2024 as well as in 2023. The two final instar larvae found in September 2023 are likely to have emerged in spring 2024. Two late instar larvae with a length of 27 mm and 37 mm were found in September 2024 and six large larval moulted skeletons were also discovered, indicating there were possibly other larvae in the pool that were not recorded. Though not previously known for *A. caerulea*, movement of large larvae could have occurred in the drought of 1995 when there was a 60% loss in 9-18mm larvae, and the remaining larger larvae were concentrated in an adjacent pool that was deeper than would be expected for the species (Smith *et al.*, 2000).

The lack of early-instar larvae can be explained by the age of the pools and their depth. There were fewer areas of shallow water of a depth of 10-20 mm with *Sphagnum cuspidatum*, which is the favoured habitat of *A. caerulea* (Smith *et al.*, 2000; Batty, 2019). This habitat is starting to develop in the trial pools and it was present in adjacent areas. The optimal habitat has also developed in some areas below the dams where the water flow has been reduced. In May 2023 2024, eight *A. caerulea* larvae sized 12-20mm were found in the runnel below pool St2 but none were found in September 2023 and 2024.

In 2024 five small *A. caerulea* larvae with a length of 10mm (x3), 14 and 15mm

Plate 8. Station pool St3 in May 2023. The outflow (far left) was dammed. The pool provided open water and is linked by a Sphagnum filled depression (in the foreground) to other infilling pools This pool had *A. caerulea* larvae on all three visits.

were found in pools below St6, the nearest being 18m away (Plate 9). These were transferred to St6a, where *Sphagnum* was colonising, to give them a better chance to complete their development (Plate 10). *Sphagnum* mats provided critical refuge for *L dubia* (Sigutova *et al*., 2021) and this is likely to be true for *A. caerulea.*

The only early instar *A caerulea* larvae found in the trial pools were in pool L6 in October 2024 where there is a complex of varied habitat and abundant *Sphagnum spp.*

Other pools in the trial area

Three other pools in the trial area consistently had *A. caerulea* larvae. These were deeper pools that maintained water during the 2021 drought:

1. Pool AH1 (NN35656662), dimensions 7 x 7 m, 40-50 cm deep. Two *A. caerulea* larvae (6 mm and 15 mm) survived here in 2021, six larvae

Plate 9. This small pool in the foreground contained early instar *A. caerulea* larvae in September 2024. It is situated 18m from the Station pools St6a and Stb6 (Frog pool) which are located behind the figures in the background and adjacent to each other.

11-16 mm in 2022, and one 12 mm larva in May 2023. However, none were found after this. The pool, though deep, was infilling with *Sphagnum* and the amount of open water had reduced from 50% to 15%. The number of *Aeshna juncea* larvae found increased and these became dominant in 2023 and 2024, providing greater competition for *A. caerulea*. There is also a possibility of the predation of *A. caerulea* larvae by the larger *A. juncea* larvae.

2. Pool WFD1, (NN35656671) had a 22 mm long larva in 2021, one of 35 mm in 2022 and a 36 mm larva in 2024 (Plate 11).

3. Pool WFD2 (NN35636669) had one larva of 11mm in 2022 and one of 37 mm in May 2023.

Thus, it appears that the species reached the final instar in the last two pools. These deeper pools were also breeding pools for *L. dubia.*

Plate 10. Station pool St6b in September 2024. *Sphagnum cuspidatum* is starting to colonise. Five *A. caerulea* larvae were transferred here with *Sphagnum*. The pool extends for 9m beyond where it appears to finish at the top of the photograph.

Leucorrhinia dubia

Leucorrhinia dubia took slightly longer to colonise than *A. caerulea*, with larvae present in two pools by September 2024 (Tables 3 & 4).

The history of *Leucorrhinia dubia* at Corrour is outlined below:

- It was first recorded on 2 September 2021 at two pools, with seven larvae 15-19mm in length at pool WFD1 and in a long narrow runnel just below this at NN35686673.
- On 2 June 2022, at pool WFD1, five adults were seen with two emerging. Additionally, five larvae 17-18mm, close to emergence, were present. A further four larva, 15-19mm, were found at the deep open pool WFD2. Larvae were reported from a third pool NN35926653, just south of the station track (NBN Atlas, 2024).
- In 2023 two exuviae were found at WFD2 in May but no larvae were seen at Corrour.

- In September 2024 eleven *L. dubia* larvae were found in two trial pools: in St1 one larva 10mm in length and, in St2, 10 larvae; sized 10mm – 13mm (Table 3). These larvae are likely to have developed from eggs laid in 2023. Additionally, a final instar larva 19mm in length was in pool WFD 2
- The larvae of *L. dubia* have distinctive dark ventral markings on the abdomen (Plate 11) and take two years to develop. Adults and larvae are usually seen in larger quantities at pools in lowland areas of Britain. In Scotland, where they are present in bog pools at higher altitude, only a small number of larvae are typically seen at individual pools.

Pool St1 was in a new area for the species. Pool St2 had the most open water and was close to the breeding pool WFD1 (Plate 12). The latter pool, however, was becoming infilled and *L. dubia* was not seen here in 2023 and 2024, presumably due to the deterioration of the habitat. *Leucorhinia dubia* has never been recorded from the Lubnaclach area.

Somatochlora arctica (Northern Emerald)

Another rare Scottish dragonfly, Near Threatened (Daguet, 2008), *Somatochlora arctica* (Northern Emerald), had not previously been recorded from the Corrour Estate. A single larva of this species was found in the *Sphagnum* runnels below pool St6a at NN3570466694. Larvae of *S. arctica* have been recorded in other areas in *Sphagnum* filled runnels and pools but these are often near woodland (Christofaro, 2023). The woods by Loch Ossian are 3 km from the Corrour site. Previously there has been just one other record - from Rannoch Moor in the western area, a similar distance from woodland (NBN Atlas, 2024). The Corrour Estate is encouraging the expansion of woodland, providing more habitat for *S. arctica* in the future.

Other Odonata species

The trial pools at Corrour also support a range of odonata species that were breeding after 18 months, nine in total including the targeted species. They were found at 13 of the 14 pools. The one pool not yet colonised by dragonflies was the new deep pool, St4 (Plate 13), which had been specifically dug for *L. dubia*.. *Libellula quadrimaculata* was the most common dragonfly and was found at 13 pools (Fig. 7); this species can survive in very peaty conditions when pools are drying up.

Aeshna juncea was recorded in eight pools, although not at the small ones, as it prefers more open, deeper water. Whilst still relatively common in the Scottish uplands, where it has a stronghold, this species is declining in England (BDS,

2021) and the rest of Europe and is now listed as Endangered on the European Red List (ICUN, 2024). The same status applies to *Sympetrum danae,* which was relatively widespread at Corrour in September 2024 and has the potential to breed in many of the pools. However, larvae generally take one year to develop and are not usually evident in pools in May, or in September after the adults have emerged (the times when our sampling was undertaken).

Pyrrhosoma nymphula (Large Red Damselfly) was recorded as larvae throughout the sampling periods in 11 pools. Other zygopteran species were restricted to the two pools with deeper open water. *Aeshna cyanea* (Southern Hawker) was observed flying over a pool in the Corrour Station area complex in September 2024. This is another new species for the estate (Stephen Corcoran *pers. comm*.)

Plate 11. *Leucorrhinia dubia* larva, 14mm long, showing the ventral markings and the yellow eyes. Photograph Graham Rennie.

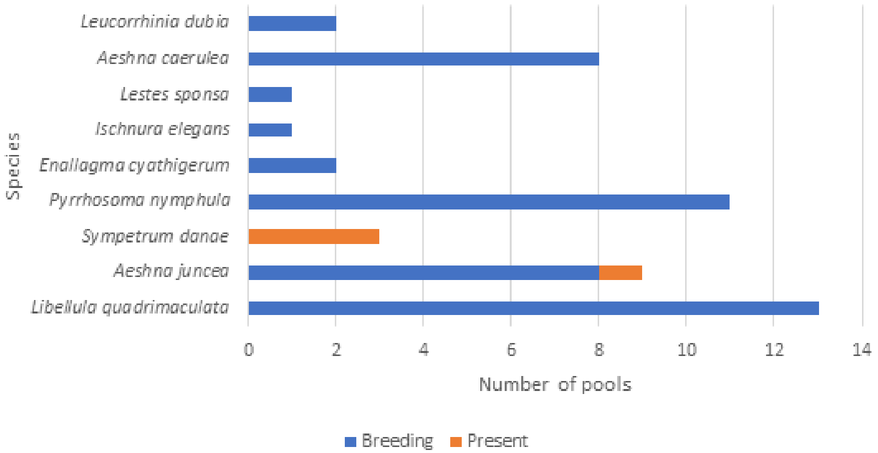

Figure 7. Odonata recorded from the trial pools at Corrour Estate. May 2023 to October 2024 (18 months after management work).

Plate 12. Station pool St2. A small peat dam was inserted on the outflow and a deeper area of >1m dug out (in the background). *Aeshna caerulea* larvae were found here on all three visits and *Leucorrhinia dubia* larvae in September 2024. Damselfly species also breed in this pool.

The range of other invertebrates recorded from the pools included: *Notonecta glauca* (Greater Water Boatman), *Corixa punctata* (Lesser Water Boatman), *Dytiscus marginalis* (Great Diving Beetle) and larvae, *Hydrophilus sp.* (Water beetle), *Gyrinidus sp.* (Whirligig Beetle), *Gerris lacustris* (Common Pond Skater) and also *Lissotriton helveticus* (Palmate Newt) tadpoles.

Future work

Nature Restoration Fund

The BDS secured Nature Restoration Funding (NRF) in November 2024 to expand the work of restoring pools and habitat for the three rare bog dragonflies. Corrour Estate is one of the priority areas targeted for this work. Restoration work near to Corrour Station was carried out in January to March 2025 with 120 pools restored in an area of 18.5 hectares.

Three other main breeding areas are included in this project, involving 10 estates from north-west Scotland, Glen Coe/Fort William and the Dundreggan/ Glen Morriston areas**.** Work is taking take place over the winters of 2024/5 and 2025/6, to be completed by March 2026.

The Scottish Government has set up a fund of £250 million with the aim of restoring approximately 250,000 ha of peatland per year over ten years. Over 18,000 ha has been restored over the past three years; much of this work is in the Highlands (ICUN, 2024). This work should also contribute towards the aims of tackling climate change and improving biodiversity.

Peatland restoration at Corrour

Corrour Estate has a gross area of circa 6000ha of peatland in need of restoration. By summer 2024 restoration on 643 ha, in collaboration with Peatland Action, had already been completed. A further 248 ha is ongoing and due to be completed by March 2025 and another 857 ha is to be restored over the next few years (Watts, 2024 pers. comm*.)*. Restoration work entails building peat dams or peat bunds in erosion gullies or eroded hag features. These create hundreds of pools across the site of all different sizes and depths. This extensive network of pools will be very beneficial to Odonata.

A survey of 27 newly created pools in two restored areas in 2024 recorded dragonfly and damselfly larvae in 26 of the 27 pools after less than 12 months (Corcoran, 2024). *Aeshna caerulea* larvae were present in three new pools and four natural pools nearby. These are previously unrecorded colonies of *A.*

caerulea in Coire Creagach and Allt a'Ghlas choire.

The movement of larger *A. caerulea* larvae into the new pools was also observed None of these new pools were seeded with *Sphagnum* and were created by blocking erosion channels. So these large larvae travelled from the very few existing pools to the new pools, possibly over distances of 50 metres or more (Corcoran, *pers comm*.). A variety of aquatic invertebrates and amphibians were also recorded from these new pools (Corcoran, 2024).

The work at Corrour described here illustrates the importance of pool creation during peatland restoration. Creating pools with a variety of shapes, sizes and depths is likely to benefit all Odonata species, including notable rarities. The scale of this project should help to bolster the important Odonata populations in Scotland.

Conclusion

Implications for future management

- The pools that proved the most successful were the pool complexes L1, L6, and St2. At these sites the peat dams were strategically placed to raise the water table and create an intricate pool network using the natural topography. Natural pools with a variety of areas and with different depths were created.
- Good places to insert dams were areas where pools are linked to others with *Sphagnum cuspidatum* filled depressions. These provide deeper refuges within reach of the shallower preferred pools, e.g. pools St3 (Plate 8), St2, St1 and L3 Pine pool.
- It proved important to create deeper areas near the dams, with a depth of 0.8 -1.5 m to provide lasting open water habitats. These deep open water areas, at pools St1 &2, were colonised by *L. dubia*. This technique also causes less disturbance to existing aquatic invertebrates.
- The reduction in water flow below the dams, as a consequence, provided shallow *Sphagnum*-filled pools and runnels.
- Small, steep-sided pools, sized 3 x 4 m with a depth of 0.7-1m deep, created when excavating material for the dams can be beneficial. The Frog pool, St6a, provided a good refuge for mature *A. caerulea* larvae. Its position was significant, being linked to other pools by damp sphagnum. Other small pools were colonised by *L. quadrimaculata* and *P. nymphula* but not *A. caerulea*. More importantly, small pools are not favoured by *A. juncea*.
- The pools with *A. caerulea* are often linked by *Sphagnum*-filled depressions

which can hold water during wet periods but can also become choked in dry weather. Given the success of the 'Frog pool', digging out a series of sections 1 x 2m with a depth of 1m along these depressions 10 - 20m apart, provided retreat areas for larvae. *A. caerulea* and *S. arctica* are both likely to benefit from these additional locations.

- The new deep, straight-sided St4 (Plate 13) pool dug for *L. dubia* was the only one not colonised by any odonate species or vegetation. A small amount of *S. cuspidatum* was transferred in 2024 to this pool but more may be needed. Pools St5, St6b, L3 and L2 have not been used as yet by *A. caerulea* larvae. *Sphagnum cuspidatum* was starting to colonise at the edge but open water was dominant. Having pools with vegetation succession at different stages means they are more likely to retain open water in future years. A number of known *A. caerulea* former breeding sites dating back 25 years are no longer viable because of infilling and a change of habitat. Thus, it is important to maintain such open pools in the mix.
- The key for management is to create a variety of pool sizes and depths in an area. Only a selection of pools should be tackled at any time in a given area. This will be good for dragonfly diversity providing habitat niches for rare species as well as a range of other species.

The trial pool restoration and creation on the Corrour Estate has proved to be a success and has provided suitable habitat conditions for rare dragonflies, enabling *A. caerulea* and *L. dubia,* to complete their life cycles during periods of drought. It was discovered that large larvae of *A. caerulea* were able to travel overland for 20 m or more to reach water as their existing pools dried out. With the increasing threat to breeding pools, resulting from ongoing climate change, this peatland pool management work will become even more critical.

The study reported here will inform future management at Corrour and other main breeding areas that are supported by Nature Restoration Funding, as well as peatland restoration more widely. Creating suitable habitat conditions for these rare species will serve as a buffer to ongoing climate change by supporting nuclei of strong populations that have the potential to 'seed' the colonisation of new areas and be beneficial to odonate survival in general.

Acknowledgements

A huge thank you to Corrour Estate for all their ongoing support, in particular to Sarah Watts for her help and enthusiasm and also to Allan Macleod for help with the 2019 survey. Thanks too for survey help from Stephen Corcoran, Ian

Plate 13. Station pool St4 in May 2023. This new, deep pool was not colonised by dragonflies in 2023 & 2024. It remained very open with little Sphagnum.

Strachan and the new BDS Scottish Officer, Jennifer Davidson who will be taking the project forward. Useful practical advice was provided by Normal Campell, contractor, and his team when carrying out the work so efficiently. Many thanks to Stephen Corcoran for his advice and for sharing his knowledge and findings. I would also like to thank Steve Cham for his help in writing the article.

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Migratory and dispersive dragonflies in Britain: Report for 2024

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Summary

The early part of the 2024 migrant dragonfly season was relatively subdued. There were, for instance, no spring influxes of *Anax ephippiger* (Vagrant Emperor) and *Sympetrum fonscolombii* (Red-veined Darter) experienced one of its poorest spring and early summer seasons since becoming a regular migrant to Britain back in the mid-1990s. The apparent low levels of general immigration did, however, provide an opportunity to assess the strength of local resident populations of species such as *Anax parthenope* (Lesser Emperor) and *Aeshna affinis* (Southern Migrant Hawker), both of which currently occur in Britain both as migrants and residents. Such resident populations, particularly of *A. parthenope,* appear to be thriving.

Immigration and internal dispersal intensified during the latter half of July and early August as hot weather set in. *Aeshna isoceles* (Norfolk Hawker) had already resumed its recent pattern of suddenly appearing in unexpected locations, but high summer saw records from areas as far apart as Cornwall and Yorkshire. This period also saw the dragonfly highlight of the year, namely the discovery of a group of *Crocothemis erythraea* (Scarlet Darter), including at least one female, near Crossways in Dorset during late July. Individuals remained at the site for several weeks, with oviposition observed on multiple occasions. These sightings raise hopes for the establishment of a self-sustaining breeding colony; indeed it is not inconceivable that an established colony is already present, its initial foundation having gone unnoticed. Other notable records during high summer included a small influx of I*schnura pumilio* (Scarce Blue-tailed Damselfly) onto the east Kent coast.

During autumn, small numbers of second-generation *Sympetrum fonscolombii* appeared in coastal southeastern England, likely reflecting immigration from the near Continent. The year concluded with a modest influx of *Anax ephippiger* in December.

Account of species

Notable sightings reported to the BDS Migrant Dragonfly Project during 2024 are detailed below; for information on events during 2023 see Parr (2024).

***Chalcolestes viridis* (Vander Linden) – Willow Emerald Damselfly**

The range expansion of this relatively recent colonist seems to have slowed in recent years, though the current reporting year saw further consolidation near the current range boundary and several new records were received from the Weston-super-Mare area of North Somerset. This apparent slowdown could indicate that the species is nearing a climate-limited equilibrium. Alternatively, it may now simply be advancing into more remote, under-recorded regions, making it increasingly difficult to track the leading edge of any continued expansion.

***Lestes barbarus* (Fab.) – Southern Emerald Damselfly**

Lestes barbarus had probably its best ever year in Britain, with strong populations noted at many established breeding sites, such as those around the greater Thames Estuary, and with several records from entirely new areas. In all, reports were received from over 20 sites. In the Penhale region of Cornwall, a series of sightings over the period 10 July to 2 September (SJ, DT) suggests the presence of an established breeding colony, following on from the discovery there of an individual back in June 2023 (CP). Elsewhere, a female spotted at West Bexington, Dorset, on 15 September (GF) is perhaps more likely a fresh immigrant, while another female seen in Richmond Park, Greater London/ Surrey, on 25 August (ML) is also of note. Not only is it the first area record, but it was found just days after a sighting there of *Ischnura pumilio*, another species normally absent from the region.

***Erythromma viridulum* (Charp.) – Small Red-eyed Damselfly**

Several individuals were seen and photographed at Parc Menai near Bangor, Gwynedd, during late July–early August (JP, JH *et al*.). This location is roughly 90 km west of the nearest known breeding sites, which lie in Cheshire, though it is possible that closer, as yet undiscovered, populations exist.

***Ischnura pumilio* (Charp.) – Scarce Blue-tailed Damselfly**

This species is known for its strong dispersive ability, and records from the far south-east of England, an area where it is typically absent, suggest some immigration from the Continent took place during 2024. A female was seen near Deal on the east Kent coast on 31 July (PY), and up to a dozen individuals

Plate 1. *Lestes barbarus*, female. West Bexington, Dorset. 15 September 2024. Photograph by G. Freeman.

were later discovered at nearby Sandwich Bay during August (SBBOT); these sightings mark the first county records. On 17 August, two were also recorded in Richmond Park, Greater London/Surrey (NA). Elsewhere, individuals noted near the coast at Felbrigg Park, Norfolk, on 29 June (SCi) and between 24–28 July (SCi, SBu) might perhaps form part of the same general influx, though they could alternatively represent local wanderers from within Norfolk, where the species is now established in small numbers.

Aeshna affinis (Vander Linden) – Southern Migrant Hawker

During the current reporting year, *A. affinis* was well recorded in England south of a line roughly between the Severn Estuary and the Wash, with records covering the period 11 June to 19 September. Many records clearly pertain to locally bred individuals, but the status of others – and consequently the extent of immigration during the year – is becoming increasingly difficult to determine. As our local breeding populations continue to strengthen, even records from unexpected areas might increasingly relate not just to immigrants from the Continent, but to local wanderers from as-yet undiscovered breeding sites or to longer-distance internal dispersers.

Notable records during 2024 included individuals seen at West Bexington, Dorset, on 28 & 29 July (MM), Pennan's Pool, Cornwall, on 1 August (EC), and Hedge End, Hampshire, on 2 August (TC). Their south coast locations, and coincidence with a period of unseasonably hot weather and southerly winds (Ventusky, 2025), may imply these sightings relate to fresh immigrants. Away from the core areas of southern England, a male present at North Cave Wetlands, East Yorkshire, between 26–28 August (PG, MR) was clearly also a long-distance disperser, though perhaps not conclusively of continental origin. An immature female observed at Chambers Farm Wood, Lincolnshire, as early as 26 June (RC), by contrast, hints at an undiscovered breeding site. In Wales, reports came from Goldcliff, Monmouthshire, on 5 August (JT *et al*.) and 16 August (LGr), as well as Dale Airfield, Pembrokeshire, on 11 August (BS). Given records from both these sites during 2023 (S. Preddy, pers. comm.; Parr, 2024), these individuals could potentially also reflect local breeding populations.

***Aeshna isoceles* (Müller) – Norfolk Hawker**

In recent years, *Aeshna isoceles* has rapidly expanded its British range with numerous sightings, often of multiple individuals, from unexpected locations and with new breeding colonies frequently emerging as a result. During 2024, records from the Avalon Marshes in Somerset between mid-May and early August strongly suggest a newly established breeding population, as do records from gardens in eastern Blackpool, Lancashire, on 1 June (FB), 25 June (SBs) and 26 July (DBi), though in this instance the exact breeding site currently remains unknown. Multiple sightings from Lower Moor, Wiltshire, during late May and much of June (SCa, SBr, LGa) may well also point to a newly formed breeding colony.

Elsewhere, there were a large number of 'one-off' records from unexpected areas, though the precise origins of these wandering individuals still remain unclear. Records included individuals seen at Isle Pool, Shropshire, on 2 June (SRE); Thorne Moors, SW Yorkshire, on 27 June (DH); Otmoor, Oxfordshire, on 28 June (JD); Attenborough NR, Nottinghamshire, on 29 June (JEc); Nosterfield Quarry, N Yorkshire, on 7 July (KG); West Bexington, Dorset, on 11 July (MM); Rimac, Lincolnshire, on 20 July (MJ); Skylarks NR, Nottinghamshire, on 30 July (AL); Thursley Common, Surrey, on 31 July (AM) & 2 August (PMa; a pair *in cop*. noted); Leighton Moss, Lancashire, on 1 August (TD); Marazion Marsh, Cornwall, on 1 & 3 August (CM); Nanjizal, Cornwall, on 2 August (MW) and finally Spurn, East Yorkshire, on 12 August (LD). Many of these sightings represent either first or second county records.

In the species' more traditional strongholds, an individual was attracted to a UV moth trap near Hickling Broad, Norfolk, on the evening of 16 August (per PT).

Plate 2. *Aeshna isoceles*, male. Otmoor, Oxfordshire. 28 June 2024. Photograph by J. Dexter.

Not only is this an unusual occurrence of itself, but it is also quite a late date for the species.

Aeshna mixta Latreille – Migrant Hawker

Some sizeable gatherings were observed in eastern England during August 2024, hinting at a degree of migration. Roughly 50 individuals were seen at Frampton Marsh in Lincolnshire on 16 August (BHe) and at the Idle Valley Nature Reserve in Nottinghamshire on 18 August (GH), while at Somerleyton, Suffolk, nearly 100 were present on 23 August (RKR). A few individuals were also attracted overnight to UV moth-traps in the region, with reports coming from Cambridgeshire on 8 August (DBa) and from near Southwold, Suffolk, on 10 August (AC). Dragonflies attracted to light frequently seem to involve migrants (Parr, 2006).

Anax ephippiger (Burmeister) – Vagrant Emperor

An unidentified dragonfly, likely of this species, was observed arriving off the sea at St Leonards-on-Sea, East Sussex, on 15 February (TI). Although a few sightings were claimed during mid-summer, all currently remain unconfirmed; the year did, however, end with a small but well-defined influx. A recently deceased male *A. ephippiger* was discovered at Winfrith, Dorset, on 8 December (RJ), while up to seven further individuals were reported from across Devon, Cornwall, and the Isles of Scilly between 18 and 28 December. Elsewhere, a sighting was also made in County Cork, Ireland, on 30 December (National Biodiversity Data Centre, 2025).

Anax parthenope **Sélys – Lesser Emperor**

This species continues to go from strength to strength in Britain, with over 350 records during the current reporting year, these spanning the period 19 May to 5 October. A good proportion of the sightings clearly relate to individuals from the growing local breeding populations that are based primarily in southern England. Early in the season a number of tenerals were thus discovered, and later in the year many records came from sites that now reliably host the species on an annual basis. Because of these growing local populations, the level of fresh immigration seen each year and the exact status of specific individuals are both becoming increasingly difficult to establish. More northerly records during 2024, such as males seen at Leighton Moss, Lancashire, on 16 July (DC), at Treeton near Sheffield, South Yorkshire, on 19 July (AD) and at North Cave Wetlands, East Yorkshire, on 31 July (HA) seem good candidates for migrants. Intriguingly, the sole Scottish record, at Mire Loch in the Scottish Borders on 28 July (CH), however, comes from a site where several individuals were present back in July 2022, with oviposition even being observed (Parr, 2023). With the generation time of *A. parthenope* being up to 2 years in length (Werzinger & Werzinger, 2001) it is not impossible that this individual could have been a ‘local’ rather than a migrant.

Libellula fulva Müller – Scarce Chaser

Libellula fulva has been steadily expanding its British range over recent decades, a trend that continued during 2024 with many sightings made well away from traditional strongholds. Notable records, presumably referring mostly to wandering individuals, included one at Dosthill, Warwickshire, on 25 May (MH), another at New Buckenham Common, Norfolk, on 29 May (NE) and one at Thurston, Suffolk, over 21–22 June (TG). The most remarkable record, however, was that of a male photographed at Wykeham Lakes, North Yorkshire, on 3 August (CB), an astonishing 200 km from the nearest known breeding colonies. The origin of this individual remains unknown.

Orthetrum cancellatum (L.) – Black-tailed Skimmer

Single individuals were noted on Tresco, Isles of Scilly, on 3 June (BW) and 9 June (AT), while on nearby St. Mary's one was seen on 6 August (PHo). The species has always been erratic on the Islands, which lie roughly 45 km off the Cornish coast, though perhaps it may soon colonise.

Orthetrum coerulescens (Fab.) – Keeled Skimmer

A female photographed on the Suffolk coast at Minsmere on 17 July (BB) is well away from the few known colonies in East Anglia and, given the location, this individual could even be an immigrant from the Continent rather than an internal disperser.

Crocothemis erythraea (Brullé) – Scarlet Darter

Although sightings were limited to just a single site, 2024 proved to be a remarkable year for the species. The following record(s) have been accepted by the Odonata Records Committee; see Roland (2024) for further details:

21 July to 11 August At least six males and one female seen and photographed at Silverlake, Crossways, Dorset (C. Rowland *et al*.)

These sightings mark a significant milestone as they represent both the first British record(s) of multiple individuals and the first confirmed presence of a female. Oviposition was noted daily between 28 and 31 July (PMo, JEv, PHa, ST, EU), and on 6 August (SCi). Although no more than five males were ever seen simultaneously, detailed analysis of wing venation patterns in photographs confirmed the presence of at least six different males. Unfortunately, photographs of females were not always sufficiently clear to identify individuals, meaning the recorded count of one should be regarded very much as a minimum.

Over the past few decades, this species – originally native to southern Europe – has been steadily expanding its range northward and it is now a well-established breeder in the Netherlands and other parts of the near Continent. Although the first British record dates back to 1995 (Jones, 1996), and there were twelve further records up to 2023, these all relate to isolated single males and the species has thus far failed to establish itself in our country. The events of 2024 rather suggest this situation may soon change. Indeed it is not impossible that, given the number of individuals present and the lack of records from other sites in England during 2024, they already document an established population whose initial foundation went unnoticed.

Plate 3. *Crocothemis erythraea*, pair in cop.. Silverlake, Crossways, Dorset, 30 July 2024. Photograph by S. Towning.

Sympetrum fonscolombii (Sélys) – Red-veined Darter

It was one of the quietest years for the species since it first established a regular presence in Britain back during the mid-1990s. In the first part of the year, occasional individuals were recorded from 17 May onward, with reports from only ten sites by the end of July; a sighting at Seton Fields, East Lothian, on 24 June (BHi) is well to the north. Dragonflies were typically recorded for just a single day and only seemed to linger at Windmill Farm in Cornwall and Winterton Dunes in Norfolk. Later in the year, during September and early October, a small wave of sightings then took place in coastal areas of south-east England, and in particular the stretch of coast between Kingsdown in Kent and Seaford in East Sussex. These sightings included several immatures, though given the low numbers of *S. fonscolombii* recorded in Britain earlier in the year, it seems unlikely they were locally bred. Instead, they were more likely dispersing individuals from the Continent. Of particular interest was an immature female attracted to a moth trap at Felixstowe Ferry, Suffolk, on the night of 5 September (NP). The final sightings of the year involved an immature male with a distinctive bent abdomen observed in the Cradle Valley near Seaford, East Sussex, from 1–3 October (RE, PMa).

Sympetrum striolatum (Charp.) – Common Darter

A female was attracted to a moth trap near Norwich, Norfolk, on the night of 3 July, while sub-mature males were similarly attracted to light at Birchall Moss, Cheshire, on the night of 28 July (CK) and near Ely, Cambridgeshire, on the night of 21 September (PR). Dragonflies attracted to light frequently seem to involve migrants (Parr, 2006).

[Exotics]

Three non-native species of Odonata were recorded from Britain as 'accidental introductions' during 2024, with most individuals found emerging from indoor tropical aquariums. The species noted were *Ischnura senegalensis* (Rambur), with at least two records; *Orthetrum sabina* (Drury), with one record; and *Crocothemis servilia* (Drury), also with one record – this last individual being discovered outdoors on a house wall. The male *O. sabina* found in Bromsgrove, Worcestershire, on 11 October (DA) is of particular note as it represents the first British record of the species, though it has already been reported as an accidental introduction in Austria (Laister *et al*., 2014). *Orthetrum sabina* has now been officially added to the British List under Category E: exotic species introduced unintentionally.

Discussion

The early part of the 2024 migrant dragonfly season was relatively subdued, likely due to low population levels in primary source areas and a lack of favourable weather conditions for immigration. Migration and internal dispersal then appeared to intensify during the latter half of July and early August as hot weather set in. The highlight of the year was the discovery of multiple individuals of *Crocothemis erythraea*, including at least one female, at a site in Dorset during late July, though whether these sightings reflect primary immigrants or a recently-established, but previously overlooked, breeding colony remains uncertain. Either way there seems a good chance that the species will go on to become permanently established in the country; if so, then *C. erythraea* will become the seventh species of Odonata to have colonised Britain since the turn of the century. Dragonfly migration then continued until late in the year. During autumn, small numbers of immature second-generation *Sympetrum fonscolombii* appeared in coastal south-east England, and given the species' poor showing in Britain during spring, these likely reflect immigrants from the Continent rather than locally-bred individuals. The Netherlands in particular had seen far more extensive arrivals than Britain back during spring (Waarneming.nl, 2025). The year concluded with a modest influx of *Anax ephippiger* during December, likely resulting from a period of warm winds directly from north-west Africa around the middle of the month (Ventusky, 2025).

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Are British Dragonflies building up a "climatic debt"? Range shifts of British Odonata,1990 to 2024.

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Summary

Where there is sufficient data to calculate occupancy at a 100 m square resolution, the change in the fifth most northerly and southerly records and the median changes in latitude and longitude have been calculated for populations of British odonates in response to climate change over the period 1990-2024. For zygopteran (damselfly) species, the average median latitude is moving north at 1.85 km/year and, for anisopteran (true dragonfly) species, at 2.86 km/year. Some species have extended their range much faster than this and faster than the estimated climate change. So, some at least will not face a 'climate debt' if there is receiving habitat availability, but many species are building a climate debt. Species that are cold-adapted or sensitive to drought and specialists that may not be able to extend their ranges, will thus need conservation action to mitigate the effects of climate change to enable their survival. *Orthetrum coerulescens* (Keeled Skimmer) has spread east over the period of study and *Aeshna grandis* (Brown Hawker) has a notably more southerly distribution than would be predicted from its European distribution.

Introduction

Climate change is becoming an increasingly dominant factor for British wildlife. Macadam *et al.* (2021) considered the climate change vulnerability of 289 British species of mayflies, stoneflies and caddisflies, and found voltinism, length of flight period, altitudinal preference and affinity to headwaters being the main risk factors. Wyver *et al*. (2023) showed that, between 1980-1989 and 2010-2019, in response to climate change, the northern range boundary for British wild bees had shifted northwards by an average of 29.4 km, which is approximately 1km/yr. The calculated centre of distribution had changed rather less.

Mair *et al.* (2014) found for British butterflies, species with high habitat availability and stable (or positive) abundance trends were better able to expand north in response to climate change. Sunde *et al*. (2023) found butterfly species richness in Finland and Sweden showed a 21% gain between 1901 and 2019.

However, the effect of temperature changes was modified by other climatic variables and by types of land use. They concluded that there was a disparity between environmental conditions, and that species preferences could limit a species ability to disperse and establish populations in changing climates and new areas.

Increasing temperatures can have many effects on the odonate lifecycle, such as muting sexual colouration (Moore *et al*. 2021) and changes in female colour polymorphism frequencies (Dudaniec *et al*., 2018); also reduced larval survival, changed and less synchronized phenology of adult emergence, and smaller wings in the adult (McCauley *et al.* 2018).

At an ecosystem level, Taylor *et al*. (2021) found that changes in the climate over the last five decades are likely to have had the greatest influence on British Odonata, interacting with other factors in complex ways. Termaat (2023) found both cold- adapted and warm-adapted species having a “moderate increase” both in Britian and across Europe, whereas Bowler *et al.* (2021) found, in Germany, generally warm-adapted species and/or running water species benefited from climate change over cold-adapted species using standing water habitats such as bogs. Holmes (2025) found specialist heathland species were losing out to generalist species in southern England in the face of habitat degradation and climate change. Dalzochio *et al.* (2020), studying lakes in Sweden, found that rapid changes in species community structure can occur over a short time, and considered them to be due to climate change and lake pH levels.

Patterson (2023) pointed out “For England and Wales, the average summer day increased by approximately 0.26°C per decade, whilst the hottest day increased by around 0.58°C per decade.” However, the Environment Agency (2025a) found that, on average, for every 1ºC rise in air temperature, water temperatures rose by only 0.87ºC. They predicted that summer maxima water temperatures (even based on the high emissions RCP 8.5 scenarios of the UKCP18 climate change projections (Met Office, 2019)), would rise by only 0.6 °C per decade by 2080 above the 1981 to 2005 levels.

Thackeray & Mackay (2023), in a review of Cumbrian lakes, found that, while the average water temperature of Lake Windermere rose by 0.8ºC from 1981-2010 to 2017-2021 (which is equivalent to 0.34ºC a decade over 23.5 years), in some nearby lakes it rose by only half this amount. Their research indicated that spring and summer months are when long-term warming is most apparent. This is a period most critical to dragonfly emergence. Furthermore, oxygen solubility in water reduces with increase in temperature and this could affect larvae, but the long-term decline in solubility was masked by other local factors in each of the water bodies studied (Thackeray & Mackay, 2023).

Climate change velocity and climate debt

Loarie *et al*. (2009) presented the concept of 'climate change velocity' to express how fast natural systems must move to stay in the same temperature zone, and estimated this globally to be a mean of 0.42 km/year. Beniston (2014) considered this concept useful as a method of public engagement and estimated "European isotherms move northwards by up to 15 km/year" However, Kosanic *et al.* (2019) calculated that "almost 90% of temperature velocities [in Germany] were in the range of 0.5 to 3 km/year".

Li & Park (2020) considered the effect of different IPCC climate change scenarios on European Odonata and predicted a shift in median latitude from 2.88 to 8.03 km/year. The northern edge of their ranges was expected to shift north at only 1.13–2.00 km/year, and the southern edge of their ranges to retract at the higher rate of 2.38–10.34 km/year. They showed that the air temperature across the European continent decreased poleward by 4.4 °C per 1,000 km, indicating the predicted temperature movements would be 6.01 to 13.24 km/year using the different IPCC climate change scenarios. They therefore expected species to build up a 'Climate Debt' as species moved north more slowly than the predicted climate change.

European Odonata ranges

La Porta & Hardersen (2024) reported that *Trithemis annulata* (Violet Dropwing) has been "moving north in Italy since 1980 at a rate of approximately 12 km per year. Upon reaching the Po Plain in 2016, this rate increased to 34 km per year." This was based on the two most northerly records for each year. This was interpreted as a response to a northward shift of isotherms between 1980 and 2020 by about 28 km/year. Therefore, even a species they considered to have good dispersal ability in the face of climate change was building up a climate debt. Olsen *et al*. (2022) found that the "centroid of [Western European] dragonfly ranges shifted by 176 km on average (median 138 km)" in the period 1988 to 2010 (about 6 to 8 km/yr) and considered zygopterans (damselflies) to be more prone to island effects, being restricted in northly movements by barriers such as the English Channel. For example, Olsen found, of the four tropical species to be identified as new for Europe since 1988, only one was a zygopteran.

Söndergerath *et al*. (2012) considered that, in general, the northern range of European Odonata ranges are influenced by climatic effects and the southern range to competition, making the southern edge of the distribution prone to more local effects.

Range of British odonates

In the UK, the northern range margin of British Odonata, defined as the mean of the 10 most extreme locations, has moved north faster than the southern edge has retracted. This was based upon a comparison of the periods 1960–1970 and 1985–1995 at a 10 km square resolution (Hickling, 2005). This phenomenon has similarly been noted in British bees (Wyver *et al*., 2023), and modelled for European *Gomphus vulgatissimus* (Common Clubtail Dragonfly) (Söndergerath *et al*., 2012). The modelling of Li & Parks (2020), however, showed a faster retreat on the southern margin than expansion on the northern margin. Söndergerath *et al*. (2012) considered local factors made the retreat on the southern margin very difficult to model.

O'Neill *et al*. (2024) calculated changes in dragonfly ranges over the period 1961–2020 and found two strategies: 1) maintaining a stable environmental niche and shifting their geographic range ('niche conservatism'); 2) shifting their ecological niche whilst maintaining a stable geographic distribution ('niche divergence'). These strategies were found among both zygopterans and anisopterans (true dragonflies).

Platts *et al*. (2019) calculated the northward movement of British dragonflies, to determine whether, as a species range shifts northwards, it would run out of suitable habitat. His analysis was based on a resolution of 10 km squares and was limited to species with at least 100 km free space to the north. The data were subject to a sampling effect. Recording in the north of Scotland has been sparse for many years, thus the distribution of some northerly species such as *Sympetrum danae* (Black Darter) and *Aeshna juncea* (Moorland Hawker) were inconsistently recorded over 150 km south of the north coast of the Scottish mainland. As more recording has taken place in recent years, and the sample size increased, species have been observed more reliably further north.

The aim of this study was to establish if British odonates are building up a climate debt using the latest data at a higher resolution and excluding time periods and species where there was insufficient recording.

Methods

Records were taken at 100 m resolution, using all records verified by the BDS with six- and eight-digit grid references in the NBN Atlas (2025). To ensure reliable data, only species with records from at least an average of one hundred 100 m squares over the study period 1990 to 2024 were included. The data were analysed for 25 species from 1990–2024. However, *Orthetrum coerulescens* (Keeled Skimmer) had records from 142 unique squares in 1990 but, in 1985, there were only 58 and, for *Pyrrhosoma nymphula* (Large Red Damselfly), sufficient recording only started in 1977, so calculations were commenced in 1990 when there were 677 records of unique squares. For four rapidly expanding species with few records before 2010, the analysis was from 2010 to 2024.

The average of the records for each year for each species with sufficient data was calculated. To make the analysis more robust to outliers the median was used rather than the average. The 5th most northerly and southerly records were taken as the four records more north and south than this were likely to be outliers. Where species have been recorded close to the north or south coast, or (as for *Cordulia aenea* (Downy Emerald) and *Orthetrum coerulescens*) where there are very few northerly records, the data were not used (Table 1). Median longitudinal movements (east/west) were also calculated, using the same method. The median latitude was also calculated in km from the base of the British National Grid (SV000000) (Ordinance Survey. [undated]).

Results

All species for which data are available have shown a northerly movement in median latitude (Table 1) except for *Platycnemis pennipes* (White-legged Damselfly) and, in the period 2010 - 2024, *Chalcolestes viridis* (Willow Emerald Damselfly) and *Aeshna isoceles* (Norfolk Hawker).

When the anisopteran and zygopteran species were grouped separately a difference was seen, with the zygopteran species 5th most northerly records moving north on average at 5.10 km/year and the median record at 1.85 km/year, but anisopteran species moved at the faster rate of 6.71 km/year and 2.86 km/year respectively. Olsen *et al*. (2022) also found zygopterans moving less than anisopterans on the European continent. Similarly, O’Neill *et al*. (2024) found British zygopterans were moving less than anisopterans and so had to evolve to cope with any environmental change.

Between 1990 and 2024, both Zygoptera and Anisoptera, on average, have extended the northern edge of their ranges faster than their median latitudes, implying a spreading out of populations rather than just moving north, as seen in Hickling *et al*. (2005), Wyver *et al*. (2023) and Söndergerath *et al*. (2012). This is most noticeable in the zygopterans *Calopteryx virgo* (Beautiful Demoiselle), *Coenagrion puella* (Azure Damselfly) and *Ischnura elegans* (Blue-tailed Damselfly) and in the anisopterans *Aeshna cyanea* (Southern Hawker), *A. mixta* (Migrant Hawker), *Anax imperator* (Emperor Dragonfly), *Libellula depressa* (Broad-bodied Chaser) and *Orthetrum cancellatum* (Black-tailed Skimmer) (Table 1).

Table 1. Changes in recorded latitude and longitude for British dragonfly species in km/year over the period 1990 to 2024 for species with an average of 100 or more unique 100m squares; also for species with 100 squares only in the shorter period from 2010 to 2023. Movements north and east are positive, south and west are negative. Also included are the median latitude in 2024 (in km north of the base of the British National Grid (SV000000)) (Ordinance Survey, undated), length of wingspan (Li et al., 2020), flight period and European temperature preferences (Li et al., 2020; Termaat, 2023).

Species	Change in 5th most northerly record (km/year)	Median Latitude or records in 2024 (km)	Change in Median Latitude (km/year)	Change is 5th most Southerly record (km/year)	Change in median Longitude (km/year)	Wingspan (mm) (Li, *et al.*, 2020)	Flight season length for 95% of adult records	European temperature preferences: STPI (ºC) (Li, *et al.*, 2020)	European temperature preferences: STI (°C) (Termaat, 2023)
1990 - 2024									
Lestes sponsa			4.27		-0.97	42.0	96	8.20	7.57
Calopteryx splendens	5.50	263	1.29		-0.19	61.0	107	9.90	9.39
Calopteryx virgo	9.30	170	1.30		2.28	58.0	107	8.90	8.95
Platycnemis pennipes	0.81	185	-1.35		0.27	45.0	92	10.00	9.43
Coenagrion puella	6.14	267	2.54		-0.13	41.0	93	9.40	9.30
Enallagma cyathigerum			1.41		0.28	38.0	119	8.70	8.46
Erythromma najas	3.77	254	2.74		-0.85	43.0	106	8.70	7.60
Ischnura elegans			1.51		0.09	35.0	112	9.40	9.82
Pyrrhosoma nymphula			2.90		-0.13	44.0	100	9.00	8.82
Average for zygopterans	5.10	228	1.85		0.07	45.2	103.6	9.13	8.81
Aeshna cyanea	10.68	255	1.77		-0.94	100.0	113	9.10	8.81
Aeshna grandis	3.28	286	1.47		-0.78	102.0	86	7.50	6.55
Aeshna juncea			9.05		-1.68	95.0	106	6.60	5.86
Aeshna mixta	8.73	260	2.98		-0.51	85.0	93	9.60	10.25
Anax imperator	8.56	241	2.01		-0.36	97.0	104	10.20	11.40
Brachytron pratense	6.72	254	3.28		0.82	72.0	56	9.00	9.02
Cordulegaster boltonii			2.58		0.36	90.0	103	8.80	8.77
Cordulia aenea			0.19		-0.37	68.0	73	8.10	7.35
Libellula depressa	8.48	221	1.62		-0.46	76.0	88	9.70	9.67
Libellula fulva	2.61	253	3.85		-0.03	74.0	71	11.00	10.33
Libellula quadrimaculata			2.45		-0.37	75.0	86	8.10	7.88
Orthetrum cancellatum	8.31	250	2.40		-0.89	77.0	88	9.80	10.41
Orthetrum coerulescens			0.16		3.14	60.0	104	10.60	11.27
Sympetrum danae			7.65		-1.24	46.5	100	7.20	6.76
Sympetrum sanguineum	3.01	256	2.14		0.56	55.0	101	9.20	9.33
Sympetrum striolatum			2.16		0.05	58.0	135	9.70	10.82
Average for anisopterans	6.71	253	2.86		-0.17	76.9	94.3	9.01	9.03
2010 - 2024									
Chalcolestes viridis	20.12	234	-0.97	-10.93	-8.30	52.5	108	11.2	10.6
Ceriagrion tenellum	-1.92	142	1.72	-0.69	1.75	36	97	11.5	12.2
Erythromma viridulum	12.83	254	0.13	-2.43	-2.78	38	83	10.7	10.6
Average for zygopterans	10.34	209.85	0.30	-4.68	-3.11	42.17	96.0	11.13	11.15
Aeshna isoceles	5.85	267	-2.97	-19.32	-1.71	84	66	10.2	10.4

Three species that are cold adapted, *Aeshna juncea* and *Sympetrum danae* (Bowler *et al*., 2021) or sensitive to summer drought *Lestes sponsa* (Emerald Damselfly) (Taylor *et al*., 2021) and *A. juncea* (Ott, 2024; Lamouille-Hébert *et al*., 2024) showed a pronounced northerly shift due to their populations being thinned out in the south (Holmes, 2025).

The southerly edge of the range could only be meaningfully calculated for three species - *Erythromma viridulum*, *Chalcolestes viridis*, *Aeshna isoceles* - all spreading out of East Anglia. Most British Odonata species have a southern distribution in Europe and even *Sympetrum danae* and *Aeshna juncea* have strongholds in the very south of the country.

Between 2010 and 2024, *Chalcolestes viridis* and *Erythromma viridulum* have also extended the northern edge of their ranges faster than their median latitudes. On arrival in the UK, these species have expanded the edge of their distribution north at over 5 km/ year. *Chalcolestes viridis* moved 20 km north, 11 km south and 8 km west a year over the 14 years from 2010 to 2024, with *E. viridulum* rather slower at 12.83 km north, 2.43 km south and 2.78 km west a year over the same period. A third zygopteran, *C. virgo*, also expanded the edge of its distribution north at over 5 km/ year while also moving east, as has been noted for some time (Tyrrell *et al*., 2009). Most species show a slight tendency for the median longitude record to move west as they move north, owing to the shape of the British landmass.

Two anisopteran species *Brachytron pratense* (Hairy Dragonfly) and *Orthetrum coerulescens*, showed a pronounced easterly shift over the time period. Tyrrell (2011) reported *B. pratense* as having expanded into the Midlands from being mainly restricted to the south coast in the 1980s. However, in the first half of the 20th century the species was consistently reported in East Anglia, with Lucas (1900) recording it as “common” in Wicken Fen, Cambridgeshire and present on the Norfolk Broads, near Lowestoft, and in Essex “near Epping” and “rare” near Colchester. Longfield (1949) considered it “fairly common locally but mostly in the south” with records In Lincolnshire, Cambridgeshire, Norfolk and Suffolk. This suggests that the species was recovering from a previous contracted range after the 1980s. Historical records for sites like Wicken Fen are not in the NBN Atlas database, biasing the calculation, and so the calculated result for this species reflects only the time span investigated.

Similarly, while the data from 1990 to 2024 shows an easterly shift for *O. coerulescens* (Fig. 1), the low number of records in the 1980s show the species strong in the west of its range. Lucas (1900) recorded the species from Kent but not from Anglia. Longfield (1949) recorded “no recent records for Cambridge, Essex, Isle of Wight or Kent” and “It is found sparsely in Norfolk, Oxford and

Hertford." However, Hammond (1983) reported only three 10 km squares before 1961 from East Anglia and none from 1961 to 1983. Even in 2006, White (2006) recorded only one extant population in East Anglia, supported by heavy management. An easterly movement up to 2012 was suggested in Cham *et al*. (2014) with three 10 km squares in East Anglia with records before 1991 and nine new squares in 2000 to 2012, together with an eastward expansion of the species range in Wales.

In Norfolk, *O. coerulescens* is now recorded on several sites. The County Recorder records of the British Dragonfly Society reported the species in Cambridgeshire as "used to breed at Wicken Fen in the 1800s but has not been recorded here since." (British Dragonfly Society, 2025). But one was recorded in the county in 2024. In Suffolk, the species was "first noted as recently as 2018" and "records of this species are apparently increasing" (British Dragonfly Society, 2025). Across the whole time period, the species has spread east across its range, in the Scottish Highlands, Cumbria over to the North York Moors and out of Cornwall and Devon. Natural England (2020) considered the species sensitive to "the direct and indirect impact of changing patterns of rainfall and abstraction on water tables, especially in the south and east of England, are likely to be the main adverse effects [on the species] of climate change." Holmes (2025) recorded declines in southern England.

The results presented here exclude two species that are specialists in the UK, *Coenagrion mercuriale* (Southern Damselfly), which Purse (2002) found to be highly restricted by climatic and habitat variables and Lévêque *et al.* (2024) found, by genetic analysis, to have low dispersal capabilities, especially among outlying populations, and *Gomphus vulgatissimus* (Common Clubtail). This exclusion was due to a lack of data, but what little data there are implies that they are not moving north or are not able to move north in response to changes in climate.

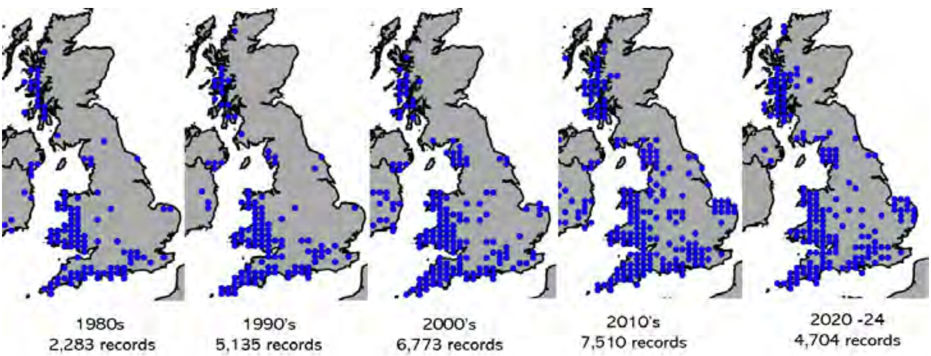

Figure 1: *Orthetrum coerulescens* distribution 1980s to 2020s (up to 2024). (NBN Atlas (2025).

The BDS Clubtail Count 2017 to 2019 (BDS, 2020) recorded a number of population losses of *G. vulgatissimus* on multiple river systems. The only indication of northward colonisation was on the River Dee. Hickling *et al*. (2005) reported a northward move of 104 km (4.16 km/year) between 1960-1970 and the period 1985–1995 but this was based on only 24 records in the British Dragonfly Society Recording Scheme in 1960-1970 in the 100 km grid reference squares SU (Thames valley), SO (Severn valley) and SQ (West Sussex), including only one record from SP (Upper Thames). None were recorded from SJ (Dee Valley), where the first record was in 1976. By the period 1985–1995 there were 1143 records for the species, with 116 records in SJ (Dee valley). The lack of records from the first period could be an artifact of lack of investigation.

Limitations of the methodology

Records in the NBN database are *ad hoc* records and highly skewed in time, with only 6,379 records across all species for the decade 1960–69, 27,556 in 1970-79, 13,3701 in 1980-89 and 276,284 in 1990-99.

The requirement for a minimum number of unique squares, excluded two species *Leucorrhinia dubia* (White-faced Darter) and *Aeshna caerulea* (Azure Hawker), which have undergone significant contractions of their southern borders in recent years (Clarke, 2014; Willet, 2013; Hickling *et al*., 2005).

The results of the study were based upon data with a greater number of records for the south than the north. The method makes no allowance for a change in recorder behaviour. But, with the British population tending to move south, for example in the period 1900 to 1991 moving 16 km south (Dorling & Atkins,1995), when the changes shown are for species largely moving north, even with fewer recorders in the North, recorder behaviour must have a minor effect. Secondly, this difference in recording should affect all species equally, yet this is not the case.

Discussion and Conclusions

In this study, all species, with the exception of *Platycnemis pennipes* in the period 1990-2024 and *Chalcolestes viridis* and *Aeshna isoceles* in the period 2010-2024 had a northwards range movement in their median latitude, demonstrating a response to rising temperatures. In *C. viridis* and *A. isoceles* an even stronger southerly expansion masked a northern expansion.

Li & Park (2020) noted that a “species temperature preference index” (STPI) calculated as the annual mean air temperature over the observed sites across their study area of Europe was the dominant driver determining their movement in response to climate change, along with that of water velocity. Two species typically on moving water *Gomphus vulgatissimus* and *P. pennipes* were found in this current study to be vulnerable, while *Calopteryx virgo* was expanding.

Platycnemis pennipes, with its move south, might be at risk from climate change. However, the British Dragonfly Society (2023) reporting the results of the White-legged Damselfly Investigation, which ran from 2018-2022, confirmed the findings of Taylor *et al*. (2021) which reported that the species had significantly increased in occupancy and was not considered a species of conservation concern. However, dynamic shifts in distribution were found with different wetland sites being abandoned and others colonised. The STPI of Li & Park (2020) and the STI of Termaat (2023) do not indicate a more northerly British distribution based on the optimal European temperature. It is interesting, and in view of climate change concerning, that with a species so dynamic in local distribution changes that no northward movement was found.

An alternative explanation to rising temperatures for the median latitude of Odonata records moving north could be that species are dying out in the south due to factors such as habitat loss, as has been found with heathland specialists (Holmes, 2025), or potentially more severe-water pollution in the more heavily populated south. So, the apparent move north of the mean could be ascribed as a result of a loss of populations in the south. However, when the occupancy trends of the species analysed were compared using the method described in Holmes (2025), while there are signs of a general decline in zygopterans, this is not the case in anisopterans. There is, therefore, no sign of stronger declines in the south than in the north.

Climate changes vary from season to season, with reduced temperature increases in Spring (Table 2). The Environment Agency (2025a) data indicated that water temperatures were rising less for every 1ºC rise in air temperature in winter than in other seasons. They also modelled a slight delay in maximum and minimum water temperatures in coming years potentially affecting odonate phenology. Their data present the possibility of using weather data to tease apart which factors are critical at which point in the life cycle of Odonata.

Li & Park (2020) considered the temperature impact of climate change but not effects of drought and lowering water tables, which are known to be important for several species (Taylor *et al*., 2021; Ott, 2024; Lamouille-Hébert *et al*., 2024). The Environment Agency (2025b) commented that “We are facing less water overall, with warmer and wetter winters, hotter and drier summers” and 15% of surface water bodies have “unsustainable levels of abstraction now” with the inevitable impact on odonate populations. “Changes to drought characteristics such as intensity and duration vary regionally, with the most pronounced

Table 2. Increase in seasonal temperatures in ºC per decade. Areal values for the U.K. from HadUK-Grid 1km gridded climate data from land surface network (Meteorological Office National Climate Information Centre, 2025).

Year range	Winter	Spring	Summer	Autumn	Annual
1990-2024	0.23	0.16	0.22	0.33	0.24
2000-2024	0.32	0.16	0.23	0.15	0.22

increases expected in the south and southeast of England”. Kirkpatrick *et al*. (2021) expressed similar concerns about increasing drought frequency in Scotland, especially on the east coast. (However, note that Kendon *et al.* (2025) at the UK Meteorological Office comment that “The UK’s climate has become steadily wetter since the 1980s, due to an increase in winter ‘half-year’ rainfall.”)

Factors affecting rate of range shifts

Li & Park (2020) and Termaat (2023) both calculated the mean temperature of the range of individual species across Europe, enabling a precise understanding of the optimal temperature requirements of each species and there is very good correlation between their calculations (0.93) (Table 3).

When all species are considered, there is a weak negative correlation between the optimal temperature requirements of each species and the rate of northerly movement -0.57 and -0.49 (Table 3): the lower the optimal temperature requirement, the faster they move north. This is because three cold-adapted, heathland specialist species, *Aeshna juncea*, *Sympetrum danae* and *Lestes sponsa*, whose declines was noted by Taylor *et al.* (2021), are retracting north and skewing the calculation. However, *Aeshna grandis* (Brown Hawker) is also considered a cold adapted species according to Li & Park (2020) and Termaat (2023) but is not moving north. When these four cold-adapted species are taken out of the calculation the correlation disappears (0.03 and 0.04) implying that the significant northerly movement is in these species. As a generalist species, *A. grandis* is maintaining a strong population in southern England (Holmes, 2025). Taylor *et al.* (2021) reported *A. grandis “* is known to have spread northwards in England, particularly along the east coast of northern England”, but no strong northerly movement is seen in the results of the present study. In Europe *A. grandis* is found much further north in Scandinavia than *A. cyanea* (Billqvist, 2023). It is suffering a decline in Germany (Bowler *et al*., 2021) while in Southern Europe *A. grandis* is considered ‘Vulnerable’ in Italy, while *A. cyanea*, is classed as ‘Least Concern’ there (IUCN, 2025) but this situation is reversed in Britian and worth further investigation.

A weak positive correlation was seen between optimal temperature requirements and an eastward spread (0.48 and 0.49) (Table 3). Winter temperatures are lower on the east coast than the west coast in Britian and this might show an increased ability for warm-adapted species to survive winters in formerly cold easterly sites.

Li & Park (2020) did not find strong evidence that species traits, such as the duration of flight or length of wingspan were important. However, the length of wingspan was relatively important under extreme climate change scenarios, indicating that once the temperature increases dramatically, species traits become more relevant. Bowler *et al*. (2021) also associated longer wingspan with increase in occupancy in Germany. McCauley *et al.* (2018) found increasing the temperature during larval development resulted in adults emerging with smaller wings, reducing their flight and dispersal ability and so limiting their potential to respond to climate change.

To analyse if this was relevant to British Odonata, the flight season length for 95% of adult records for each species, ignoring the earliest and latest 2.5% of records to avoid outliers, was calculated and compared with the rate of northward movement of the 5th most northerly record or the median latitude data and no correlations were found (Table 3). Similarly, the wingspan for each species from Li & Park (2020) was compared with the rate of northward movement of the 5th most northerly record or the median latitude data and weak correlations were found (Table 3).

Suárez *et al*. (2019) found larger zygopterans to be more likely to be at conservation risk and suggested this was potentially due to an on average longer developmental period and so potentially more vulnerability to anthropogenic impacts reducing prey size and number, implying that not all species evolve successfully. It is not clear that Suárez's argument holds, since, by this argument, anisopterans should be even more at risk than larger zygopterans.

Anisopterans can use thoracic muscle vibrations to heat their body and to a certain degree regulate their haemolymph circulation. These are adaptations which damselflies lack, so the two groups are affected differently by temperature, with anisopterans in general more tolerant to high and low temperatures than zygopterans (Olsen *et al.* (2022).

If zygopterans are moving north more slowly and are more likely to be blocked by ecological barriers than anisopterans, over time there should be proportionately more anisopterans in the north than in the south of the country and the proportion of anisopterans to all odonate records across the whole country should increase. However, these effects are not yet realised. While about 49% of all Odonata records on the NBN database are Anisoptera in the

Table 3. Correlations between the European optimal temperatures of species using the STPI (ºC) calculated by Li *et al.* (2020) and STI (°C) calculated by Termaat (2023), wingspan (mm) and flight period (days) for 95% of the adult records **and** change in 5th most northerly record (km/year), median northing ('latitude') of records in 2024 (km), change in median latitude (km/year) and change in median longitude.

	European optimal temperature.			
	STPI	STI	Wingspan	Flight season
Changes in 5th most northerly record	-0.02	0.31	0.46	0.26
Median northing of records	0	0	0.33	-0.17
Change in median latitudes	-0.57	-0.49	0.13	0
Change in median longitude	0.48	0.49	-0.23	0.04

south of the country, the figure only rises to about 51% in the north, with wide fluctuations across the country. The proportion of anisopterans to all odonate records across the whole country remained between 49.5% and 50.0%, again with fluctuations, in the period 1990 to 2024.

Dudaniec *et al*. (2018) performed genetic analysis on samples of *Ischnura elegans* at different latitudes in Sweden and found changes to heat shock, ion transport and opsin proteins. These they considered relevant for adaptation to local climatic conditions for thermal stress response, cold temperature adaptation and mate discrimination. Within their study area, the frequency of *I. elegans* gynochromes increased with latitude and was considered to improve cold tolerance that may facilitate range shifts, and the change in opsins was considered optimised in response to this for sexual selection. This valuable work needs to be extended to enable comparison with other species, as not all species might adapt so specifically to local climatic conditions. For example, Simonsen *et al.* (2021) found from genetic studies that *Orthetrum cancellatum* showed more local genetic variability than *Orthetrum coerulescens*. *Orthetrum coerulescens* was found to mix freely across the Mediterranean, questioning the validity of proposed subspecies and so making local adaptation to climate less likely.

Minot & Husté (2022) found "low genetic differentiation and no pattern of isolation by distance" among mainland European populations of *Anax imperator*, suggesting historical or current movements of individuals. Only the U.K. population presented a significant genetic differentiation from other European populations and had low genetic diversity, suggesting possible isolation of this population, with the English Channel probably acting as a barrier to gene flow.

If British and European odonate populations were 1) identical genetically and 2) identical in habitat preferences and 3) there is no climate debt, in principle there should be a correlation between the median point of the species' British range and their optimal temperature calculated from their European distribution. However, there is no such correlation (Table 3) with either of the temperature metrics available, Termaat's (2023) "STI" or Li & Park's (2020) "STPI". Note that there is an offset between the calculated median latitude and the median latitude of the actual species population due to the southerly focus in recording, but this is to the same extent for all species. *Aeshna grandis* again stands out as having a colder European temperature preference than its median British latitude implies. With such a striking anomaly, it is worth investigating if the species in the UK is more genetically related to southerly populations of *A. grandis* by a founder effect than to more cold-adapted northerly European populations.

Erythromma najas and Calopteryx virgo also have colder European temperature preferences than their median British latitudes imply. On the other hand, *Anax imperator* and *Libellula fulva* have a warmer European temperature preference than expected from their median British latitude, suggesting that they are not going to expand much further north. Note that a single temperature metric does not allow for the whole temperature band in which a species can optimally function.

Comparing the average temperature of British and European distributions of different species might uncover other anomalies, pointing to genetic differences between the island and continental populations.

Are British Odonata building up a 'Climatic Debt'?

The Meteorological Office (2025) temperature data showed an increase of 0.24°C per decade over the period 1990 to 2024, comparable with the data of Patterson (2023). It is noticeable that the concept of climate velocity is not used by the Meteorological Office (2025) and they give no single figure for British climate velocity.

Li & Park (2020) calculated the predicted temperature movements of different IPCC climate change scenarios to be 6.01 to 13.24 km/year across the European continent. The concern was that species that are not moving at this rate will build up a 'Climate Debt'. Adult anisopterans can certainly disperse faster than any of these climate velocities, but the average anisopteran is only extending its northern edge by 6.71 km/year and the median latitude by only 2.86 km/year, making a build-up of Climate Debt likely.

With *Chalcolestes viridis* extending its range north at 20 km/year, so at least some zygopterans can avoid a climatic debt. However, receiving habitat availability will override the dispersal ability of a species and govern the final range shift (Li & Park, 2020). It is noticeable that the two zygopterans extending their range fastest are *C. viridis* and *Erythromma viridulum* which are both new to the country, having been held up by the barrier of the English Channel, and are now expanding into suitable habitat. However, zygopterans on average are extending their northern edge by 5.10 km/yr, and the median latitude by only 1.85 km/yr, showing that the group is building up a significant climate debt.

Receiving habitat availability rather than adult dispersal ability seems to be the limitation on odonata range shifts. But, if this were the sole factor, then zygopterans should move as fast as anisopterans, which they do not, showing that dispersal or potentially some third factor also plays a part.

An alternative strategy to shifting geographic range to maintain a stable environmental niche is to maintain a stable geographic distribution and shifting ecological niche. O'Neill *et al*. (2024) found examples of both among both zygopterans and anisopterans. However, in *Ischnura elegans*, whose northern edge of the range is moving faster north than the average zygopteran, Dudaniec *et al*. (2018) found genetic local adaptation, suggesting that, for the truly successful species, both strategies can be adopted. Work to establish if *I. elegans* is typical, or if species at risk do not have this local adaptation, would be useful. Such studies would also help quantify the extent to which species are dispersive or not as was demonstrated with *Orthetrum sp.* by Simonsen *et al*. (2021).

While there are some species which are moving faster north than predicted climate change, many are not. Three groups seem likely to require future conservation action:

1. Species that are cold-adapted, such as *Sympetrum danae* and *Aeshna juncea*, or those sensitive to drought, such as *Aeshna juncea and Lestes sponsa,* that have already contracted their range from the south of the UK.

2. Some specialist species such as *Coenagrion mercuriale* and *Gomphus vulgatissimus* that are especially vulnerable.

3. Zygopterans in general which, both in Britain and across Europe, tend to be less mobile, more obstructed by ecological barriers, and are in general less tolerant to high and low temperatures than anisopterans.

We are seeing real effects of climate change on British dragonflies with a climate debt build-up in many species. While local conservation measures will help, this is difficult to do at a landscape and national level and shows the urgency of keeping to our climate neutrality commitments both individually and as a society.

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Eye and antenna cleaning in flight in *Cordulia aenea* (Linnaeus) (Downy Emerald) and *Somatochlora metallica* (Vander Linden) (Brilliant Emerald).

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Summary

Eye cleaning while in flight requires great agility and co-ordination by a dragonfly and is reported here in *Cordulia aenea* (Downy Emerald) and *Somatochlora metallica* (Brilliant Emerald) for the first time. Using a Canon R5 Mk2 camera firing at 30 fps, males of both species were recorded using their forelegs to rapidly clean their eyes and antennae whilst in flight.

Introduction

Cleaning by self-grooming is defined as any behaviour related to the maintenance and care of body surfaces and is an innate behaviour found across a wide range of animal species. Insect cuticles are frequently exposed to a variety of inorganic and organic particles, which can disrupt normal function or hinder essential physiological processes, ultimately decreasing survival rates. As a result, insects, including odonates, dedicate a considerable amount of time to self-grooming of body surfaces to eliminate debris and keep the wings clean for flight (Piersanti *et al*., 2024).

Cleaning is an important part of the daily behaviour of odonates. For optimal activity, individuals will frequently clean their wings, abdomen, legs, eyes and antennae. Most species do this while perched (Corbet, 1999; Rüppell & Hilfert-Rüppell, 2024). Many species of Anisoptera will also clean their abdomen, wings and legs while in flight, e.g. *Aeshna mixta* (Cham, 2006) and *Cordulia aenea* (pers.obs.). Eye cleaning, however, has not been reported while in flight.

The sequence of cleaning of various body parts of odonates at rest and in flight is well documented (Cham, 2006; Corbet, 1999; Heymer, 1972; Kaiser, 1974; Rüppell & Hilfert-Rüppell, 2024). Blogs and videos are available online that show various aspects of cleaning behaviour in odonates, including eye cleaning while perched (Smith, 2012; YouTube 2019: YouTube, undated). However, none show eye cleaning while in flight.

Vision is one of, if not the most, important sense of odonates. The compound eyes, combined with the antennae, are essential for sensing the surrounding environment, catching prey, finding and engaging with potential mates, defending against rivals and avoiding predators. Keeping their eyes clean is a critical activity. Whilst flying, odonates are likely to encounter very small air borne particles, such as pollen, which adhere to various parts of their bodies (Plate 2). They need to keep the surface of the eyes and antennae clean to guarantee the functioning of their visual system. Eye cleaning using the forelegs is typically observed while individuals are perched (Rüppell & Hilfert-Rüppell, 2024). The forelegs, which are furnished with specialized nano-structures, revealed by high magnification light and electron microscopy, are used for cleaning the surface of the eyes and antennae (Piersanti *et al*., 2024). Studies of cleaning using captive *Ischnura elegans* (Blue-tailed Damselfly) show that a scraping action is used while the damselfly is perched with the antennae and eyes always cleaned together (Piersanti *et al*., 2024).

Methods

The observations reported here were made at lakes at Wasing in Berkshire (SU578633), where *Cordulia aenea* (Downy Emerald) is abundant, and at Warren Heath, Hampshire (SU777587) where *Somatochlora metallica* (Brilliant Emerald) is regularly seen. Close approach facilitated many photographs of flight behaviour to be made during the flight period of both species. One cannot plan to photograph specific aspects of flight behaviour and hence events such as cleaning are taken opportunistically. Over a period of several hours during each visit, many rapid flight sequences were taken at small bays at the lakes where *C. aenea* and *S. metallica* males were patrolling.

Photographs of males in flight were taken handheld with a Canon R5 Mk2 camera and a Canon EF100-400 L lens. The aperture was set at f8 with a shutter speed of 1/3200 second and auto ISO. The camera was set to take the maximum of 30 frames per second (fps). The capture time code recorded in the metadata of each image was confirmation that 30 fps had been recorded by the camera during each sequence. The camera takes 45 megapixel images, and a 256GB CF Express memory card was used to ensure the maximum write speed to the card as images were being taken. The lens was prefocussed manually, approximately to where the patrolling males were likely to appear. As a male approached, the camera’s autofocus was activated using a back button on the camera and the sequence taken by activating the shutter button. The shutter was continuously fired until the male moved away. This method enabled the autofocus to lock on to the subject and maintain focus on the flying dragonfly throughout the sequence.

All images were imported into Adobe Lightroom and flight sequences reviewed to reveal any unusual behaviour or flight attributes.

Observations

Many sequences of the flight of male *Cordulia aenea* were recorded but there were fewer for *Somatochlora metallica* males. The cleaning of legs and abdomen while flying was often observed in *C. aenea* (pers.obs.). This involved the abdomen being curled under the thorax and the hind legs used to scrape away any detritus from the abdomen (Plate 1). The legs were cleaned by rubbing them together using any combination of the hind and middle legs to remove debris to complete the cleaning process (Plate 2).

During a rapid burst of 85 images, lasting 2.83 seconds, (taken at 09.18.21 on 31 May 2025) a hovering male *C. aenea* was recorded cleaning both of its eyes and antennae while in flight. From the total sequence only two contiguous frames showed the male cleaning its antennae, followed by its eyes, during hovering flight, before resuming patrolling. The photographs showed both front legs were used to firstly scrape across the antennae followed by the eye surfaces (Plate

Plate 1. *Cordulia aenea* male cleaning its abdomen using the hind legs to scrape away debris. The middle legs are tucked up under the thorax and the forelegs remain tucked up behind the head.

Plate 2. *Cordulia aenea* male cleaning its legs by rubbing the nearside hind leg and middle leg together. The forelegs remain tucked up behind the head. NB. small particles, possibly pollen grains, can be seen on the abdomen and thorax.

3b & 3c). In this sequence all the preceding (Plate 3a) and subsequent (Plate 3d) images showed the front legs to be tucked up behind the eyes in normal hovering flight mode and then, after cleaning, continuing normal patrol flight. A burst of 66 images of a flying male *S. metallica,* lasting 2.2 s (taken at 08.40 on 22 June 2025) showed just three contiguous frames in the sequence where it was cleaning its eyes (Plate 4).

The duration of each frame in a rapid sequence taken at 30 fps represents 33 milliseconds (0.033 of a second), with the two images of the combined antennae and eye cleaning of the *C. aenea* male taking approximately 66 milliseconds. During this brief bout of eye cleaning the photographs also showed the body twisting slightly, while the head remained level, which indicated that this individual

Plate 3. Four contiguous frames from a flight sequence taken at 30fps of a *Cordulia aenea* male cleaning its eyes and antennae. (a) normal flight with forelegs held behind the head; (b) cleaning antennae with forelegs; (c) cleaning the eyes with forelegs; (d) resumption of normal flight with legs tucked behind head. (Insets show magnified views).

was controlling and maintaining level flight while self-grooming in flight. The sequence of the *S. metallica* male showed the use of the front legs to clean the eyes and antennae over three frames, taking approximately 99 milliseconds. This was also performed at the moment it turned to change direction by twisting the body while the head remained level (Plate 4).

Discussion

Abdomen and leg cleaning in flight are relatively slow processes and have previously been recorded in image sequences taken at 12 fps on earlier camera models (Cham, 2016). In contrast, eye cleaning in flight at these frame rates has previously gone unreported, probably due to its brevity and unpredictability. At the higher frame rate of 30 fps the first records of eye cleaning in flight in *C.*

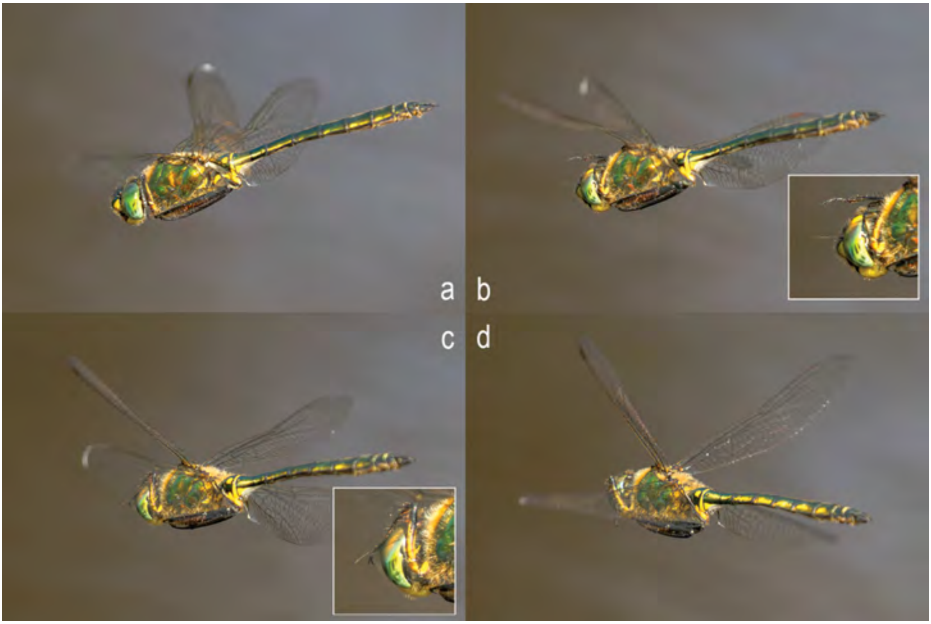

Plate 4. Four contiguous frames from a flight sequence taken at 30 fps of a *Somatochlora. metallica* male cleaning its eyes and antennae. (a) normal flight with forelegs held behind the head; (b) forelegs extended preparing to clean. NB. the nearside antenna is straight before contact; (c) forelegs cleaning eyes and antennae. The nearside antenna is pushed downwards by the leg as it scrapes across the surface of the eye; (d) Resumption of normal flight with forelegs returning to a position behind the head as the dragonfly turns away. (Insets show magnified views).

aenea and *S. metallica* have been possible. Unlike typical cleaning behaviour while perched, a search for references relating to eye cleaning while in flight did not yield any published information (Google Scholar, 2025; ResearchGate 2025). This likely reflects the difficulties in recording cleaning behaviour in flight under controlled or experimental conditions.

Males of *Cordulia aenea* and *Somatochlora metallica* patrol and defend territories along the margins of lakes and large ponds. In both species, patrol flight is interspersed with frequent bouts of hovering in areas where females are likely to be encountered (the rendezvous site of Corbet (1999)). Males will actively engage with rivals that encroach in their patrol territory. When the density of *C. aenea* males is high the patrol length becomes shorter, and clashes between males are frequent (Brooks *et al*., 1997). Similar observations have been reported for *S. metallica* (Cham, 2022). Studies of *C. aenea* have also shown that males engage in time-sharing and the territory holder always wins clashes with other males (Brooks *et al*., 1997). It therefore pays for the resident male to stay and patrol on territory for as long as possible to maximise the chances of encountering a female. Unlike libellulid species, males of *C. aenea* and *S. metallica* rarely perch at the breeding site. Keeping the eyes and antennae clean while flying is therefore beneficial to an individual male to maintain optimal vision while defending a territory and increasing his probability of encountering a female.

For a flying dragonfly any contamination on the eyes or antennae can potentially impede its visibility and manoeuvrability. Cleaning that requires a male to leave the water and perch reduces the likelihood of encountering a female. The observations described here show that eye and antennae cleaning take place very rapidly and provide further support to the incredible agility of odonates during flight. Eye and antennae cleaning in flight takes place in a fraction of a second (<0.1s) and requires great agility and co-ordination while maintaining level flight.

Digital still photography enables high resolution images of dragonflies in flight to be recorded and provides a useful tool to study behaviour. The subject recognition and autofocusing precision of the latest generation of mirrorless cameras enables hi-resolution detail to be recorded at high frame rates that would prove challenging to other video-based technologies. Dragonfly flight has been well documented under controlled conditions, yet this rarely shows other aspects of their behaviour. Rüppell & Hilfert-Rüppell (2024) have recorded many aspects of the behaviour of odonates using high-speed and slow-motion videography, yet have not reported eye cleaning in flight. Whilst video cameras are capable of much higher frame rates (>120 fps), the autofocusing technology is currently not reliable enough to lock focus on to the subject with the same precision and record the level of detail as a high megapixel mirrorless camera used in still photography mode. Professional high-resolution and high-speed video cameras with 500-1000 fps make it possible to record rapid sequences and determine exact times of behaviour, although the manual focusing required reduces the success rate of recording a moving subject (G. Rüppell, pers.com.).

Recording at 30 fps with fast autofocus on a mirrorless still camera has provided new detailed insights to dragonfly behaviour, providing a new way of documenting the fastest mobile processes in the macro range which are too brief to be recorded by observation alone. Eye cleaning while in flight is reported here for two species, yet this behaviour may be more widespread, albeit unrecorded, amongst other species. Camera technology is rapidly improving and affordable to many naturalists, and the increasingly higher frame rates of 100 fps or more, combined with faster and more reliable autofocusing, are becoming available on still and hybrid cameras that will open up new areas of study.

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Studies of Water Quality and Habitats in Relation to Site Selection in Neighbouring and Visually Similar Lakes by *Coenagrion pulchellum* (Variable Damselfly) (Vander linden) in Northamptonshire.

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Summary

Site selection by *Coenagrion pulchellum* (Variable Damselfly) has long presented a conundrum in our understanding of why this species breeds in some sites but not in others, even adjacent ones, despite them appearing the same. Differences in water quality have been proposed as an explanation for this, in relation to eutrophication and turbidity. Habitat differences are also thought to play a part. This study looks at water quality attributes and habitat differences in breeding sites in Northamptonshire, by comparing breeding sites with visually similar sites and with adjacent lakes in neither of which does *C. pulchellum* breed. The results show that breeding sites shared a combination of high dissolved oxygen (DO), dead floating leaves and stems of *Sparganium erectum* (Bur Reed)and *Typha latifolia (Bulrush)*, floating, near surface stems of *Ceratophylum demersum* (Rigid Hornwort) and the presence of *Nymphaea* sp. (Water Lily).However, several non-breeding sites also shared these characteristics so further work is required to understand more completely site selection cues.

Introduction

The habitat preferences of *Coenagrion pulchellum* (Variable Damselfly) are enigmatic and, even across the UK and Ireland, there are apparent contradictions in its preferences. It is more common and widely distributed in Ireland than Britain, and on the west coast of Ireland is limited to oligotrophic waters (Cham *et al.*, 2014). In Scotland there is an association with mesotrophic lochs. It is also frequently stated in the literature that habitats have extensive emergent vegetation (e.g. Cham *et al.*, 2014), something which may be restricted in oligotrophic (and to some extent) mesotrophic waters. A cause for species decline is thought to be through a decline in water quality through eutrophication, whether that be through excessive growth of vegetation, removal of vegetation

Table 1. Nitrate and phosphate levels in water classifications. Figures for phosphate have been converted from phosphorus and rounded to two decimal places. Data from Wikipedia (2025) & L.G.Sonic B.V. (2025).

Nutrient	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Nitrates	<0.30ppm	0.30 – 0.50ppm	0.50 – 1.50 ppm	>1.50ppm
Phosphates	<0.04ppm	0.04 – 0.07 ppm	0.07 – 0.29ppm	>0.29ppm

or increase in water nutrients (Cham, 2025). Yet Nelson & Thompson (2004) stated that, in Ireland, it is less abundant in oligotrophic and eutrophic waters, implying that mesotrophic waters are preferred.

Water bodies are classified according to their nutrient enrichment levels as either oligotrophic (low nutrients, low biological productivity and good water quality), mesotrophic and eutrophic (high nutrient levels, high biological productivity and poor water quality). Hypereutrophic waters are those with very high levels of nutrients that often lead to algal blooms which starve the water of oxygen, to the detriment of some aquatic organisms. These classifications take into account a number of factors, including turbidity and chlorophyll levels (Lake County Water Atlas, 2025), as well as nutrients such as phosphates and nitrates. Levels of these nutrients are used to define ranges for each classification (Table 1) (Wikipedia, 2025; L.G. Sonic B.V., 2025).

Nutrient levels alone do not fully describe water quality, and a number of other attributes should be included to get a fuller picture (Mike Averill, pers. com.) that can readily be measured in the field, unlike chlorophyll levels which are more complex:

- Dissolved oxygen
- pH
- Nitrates
- Phosphates
- Ammonia
- Turbidity

It is possible to combine nitrate and phosphate levels, turbidity and chlorophyll into a Trophic State Index (Lake County Water Atlas, 2025) which, as it contains most contributory elements, provides a useful single number for depicting the likely water quality.

Cham (2025) illustrated the distribution of *Coenagrion pulchellum* in Great Britain and indicated distinct clusters in East Anglia, East Midlands, South East and South West England and South West Scotland. This distribution (Cham, 2005) closely resembles the distribution of eutrophic waters published by JNCC (2025) (Fig 1). While not a definitive relationship, there is a clear suggestion that *C. pulchellum* favours eutrophic waters, except in East Anglia and South-East England, where *C.pulchellum* appears to have a relationship with Oligotrophic-Mesotrophic waters. Vegetation growth in eutrophic water is more productive than in oligotrophic and mesotrophic waters, implying that *C.pulchellum* favours eutrophic waters, perhaps because of the vegetation that grows in them. Increased eutrophication can lead to losses or unfavourable habitat (Taylor *et al*., 2021), but it is not clear at what level this might occur. Merritt *et.al*. (1996) discussed the idea that *C. pulchellum* can tolerate acidic conditions and appears to decline as sites become eutrophic. Corbet (1999) discussed the use of visual cues in site selection, where both reflected colour and shape play a part in ensuring the correct type of vegetation is selected for oviposition. There is also evidence that Odonata can have a repertoire of vegetation that they will oviposit into, which depends on substrate hardness and location in the water (Corbet, 1999). This links site selection with water quality, in that favoured ovipositing substrate may only grow well in water of a certain quality.

Coenagrion pulchellum is a relative newcomer to modern-day Northamptonshire, historically being limited to one site near Peterborough for many years (Maxey Pits), part of the VC32 recording zone. In recent years it has expanded greatly and has now been recorded breeding at four sites, with a couple of other potential sites where only adults have so far been recorded (Tyrrell, 2019). The main site in Northamptonshire is the fishing lake at Wicksteed Park, Kettering, where annual records exceed 100 adults (Cham, 2025). Tyrrell (2019) reviewed these sites and concluded that one factor common to all sites was the presence of *Nymphaea* species (Water Lily), such as *Nymphaea alba* (White Water Lily) and *Nymphaea marliacea*. Since the discovery of a small colony at Ring Res, part of the Irthlingborough Lakes complex, managed by Wildlife Trust BCN, this is no longer the case as this lake does not contain any *Nymphaea* species.

Tyrrell (2019) showed a Google Earth image of Maxey Pits and identified the position of the breeding lake relative to others in the complex of former gravel pits. Visually, the non-breeding lakes show high levels of algal bloom, consistent with hypereutrophication, whereas the breeding lake looks clear. Cham (2025) hypothesised that this was due to turbidity differences. Due to overgrowth and other access restrictions, this site was not surveyed for this study.

Thus, it appears that site selection in *Coenagrion pulchellum* is a complex combination of water quality and habitat, and Cham (2025) concluded his study with a recommendation that water quality be studied to help our understanding of this species' habitat requirements.

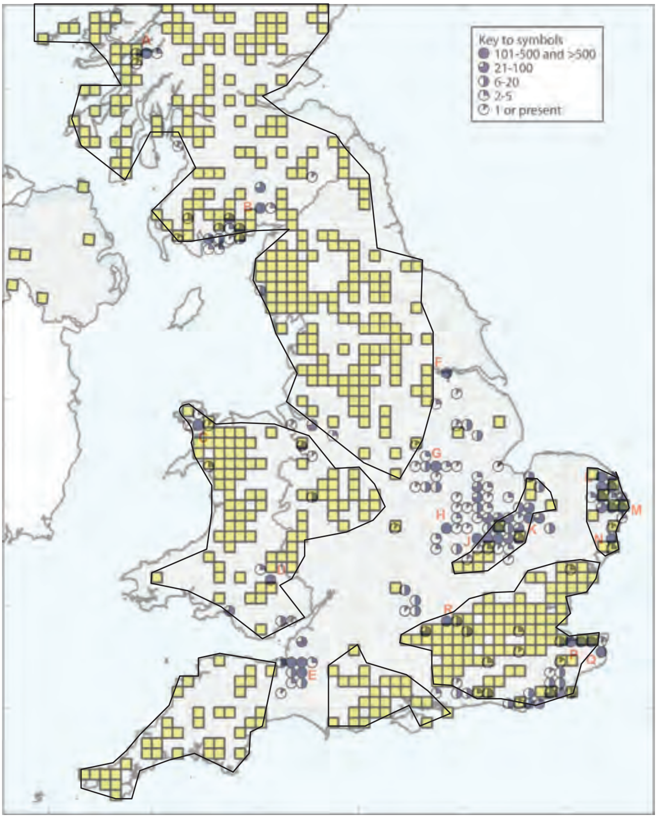

Figure 1. The distribution and abundance of *Coenagrion pulchellum* (shown as dots) (from Cham, 2025 - used with permission) overlaid with the distribution of Oligotrophic – Mesotrophic waters (shown as squares) redrawn from JNCC (2025).

Materials and Methods

A range of methods for measuring water quality is available, ranging from simple, low-cost colour change dip-tests or reagent-based kits, for example by EarthWatch Institute (2022), to high-end measuring devices, for example from Hanna (Hanna Instruments, 2025). For this study, a range of colour-change dip-tests and reagent tests were selected, marketed primarily to measure the quality of drinking water and aquarium waters. These require matching the colour from a test strip to a chart and reading off the value of the chosen parameter. This approach, although providing quantitative data, should be treated with caution due to observer variability and accuracy of the test kits, especially when detecting intermediate values. The data should be considered relative to each other rather than absolute, such that the numbers generated for this work should not be compared with numbers measured elsewhere. However

Table 2. Test parameters, kit supplier and type of test.

Test Parameter	Kit supplier	Test Type
Phosphate	Salifert, Holland	Colour change using reagents
Ammonia	Maidenhead Aquatics.co.uk	Colour change dip-test
Dissolved oxygen	Salifert, Holland	Colour change using reagents
Nitrates	Salifert, Holland	Colour change using reagents
Others:	20 in 1 test from Alevial Ltd	Colour change dip-test

the relative relationship between different sites is valid as all sites were tested with the same batch using the same methodology, providing consistent data.

In addition, measurements of other parameters such as hardness and amounts of carbonate, sulphate and chlorine were carried out using commercial kits (Table 2). Turbidity was the most difficult to assess quantitatively due to the high cost of the test equipment, so a visual assessment was performed using a turbidity chart (Plate 1).

All water quality assessments were carried out during the main oviposition season of *Coenagrion pulchellum* in Northamptonshire (May-June), following the instructions for each kit. Site selection for the water quality tests was based on the following criteria (Table 3):

a) breeding colony of *Coenagrion pulchellum*

b) proximity to a known breeding colony

c) sites with a visual similarity to known breeding sites.

In addition to sampling water quality, records of the species present at each site were taken from the authors own recording, and data uploaded to iRecord (iRecord, 2025) for the previous 5 years (including 2025). Observations of the dominant vegetation were also made. The Odonata records are classified according to the system used by the British Dragonfly Society, available by using their species recording form in iRecord. For sites where no evidence of breeding has been obtained, the adult (Ad) category was further split into AdS for adults seen in single years and AdM for adults seen in multiple consecutive years. AdM records suggest that there may be a breeding population but this needs to be established definitively. For data analysis, all records of ovipositing, exuvae and adult emergences were included as evidence of breeding.

To determine which factors are likely to be relevant, a single factor ANOVA in Microsoft EXCEL was used. A 95% confidence limit (P=<0.5) was used to reject the Null Hypotheses.

Plate 1. Visual NTU scale for assessing Turbidty. ©WOW (1999 - 2004).

Table 3. Water sampling locations and selection criteria of sites tested in this study.

Site name	British Grid Reference	Selection criteria
Weldon Woodlanp Park	SP91948933	Breeding site for *Coenagrion pulchellum*
Wicksteed Park Boating Lake	SP88127638	Proximity to breeding site
Wicksteed Park Fishing Lake	SP88167628	Breeding site for *Coenagrion pulchellum*
Barnwell Country Park North Lake	TL03588757	Breeding site for *Coenagrion pulchellum*
Barnwell Country Park Mid Lake	TL03488739	Proximity to breeding site
Barnwell Country Park Mill Lake	TL03698719	Proximity to breeding site
Irthlingborough Lakes Ring Res	SP94556936	Breeding site for *Coenagrion pulchellum*
Irthlingborough Lakes Dragonfly Lake	SP95247004	Proximity to breeding site
Irthlingborough Lakes Cotton Reel	SP94676928	Proximity to breeding site
Ditchford Lakes	SP93036795	Visual similarity to breeding sites
Finedon Pocket Park	SP91177282	Visual similarity to breeding sites
Summer Leys Toad Pond	SP88946420	Visual similarity to breeding sites
Stanwick Lakes Visitor Centre Lake	SP96517117	Visual similarity to breeding sites

Results

In Northamptonshire, *Coenagrion pulchellum* breeding sites support a higher number of breeding odonate species (Table 4a) than non-breeding sites (Table 4b). This difference was highly significant (P=0.0005). While this is not causal, it does imply that *C.pulchellum* breeding sites are generally better suited, for whatever reason, for a wider range of Odonata.

All sites featured in this study are characterised by having very hard (magnesium & calcium ions >180ppm (drinking-water.org, 2025), eutrophic, alkaline water with a pH in the range 7.2 – 8.4 (Tables 5 a, b & c). Turbidity levels in all cases were very low (>50NTU is considered turbid (Water Quality Association, 2025)) but slightly above the control tap water, so have scored <10 NTU as some suspended particles could be seen in all samples. As no reliable quantitative data on turbidity were obtained, no further analysis was undertaken.

The ANOVA analysis of the water quality parameters, Table 6, suggested that dissolved oxygen (DO) levels are slightly different between breeding and non-breeding sites in close proximity (P=0.07). There was no significant difference for any of the other water quality parameters tested.

At some sites in close proximity to breeding sites, such as the Irthlingborough Lakes complex, there are some differences in vegetation that might help explain why they are not selected by *C. pulchellum* (Table 7). Sites with large expanses of *Sparganium erectum* (Bur Reed), *Ceratophylum demersum* (Rigid Hornwort), *Typha latifolia* (Bulrush) and/or *Nymphaea* sp. (Water Lily) appear to be favoured for breeding as they seem to provide optimum ovipositing substrates.

Discussion

Test Methodology

While the chosen test methodologies gave fast and indicative results in the field, for some critical tests (Nitrates and Phosphates), the dip-test method did not give the resolution of measurements necessary for the low levels of these compounds. While eutrophic water is defined as 0.5-1.5 ppm (Table 1), the Alevial test used has gradations for 0, 10, 25, 50 ppm, making it unsuitable. The reagent tests offer alternative ways of increasing resolution for low levels but, at this level, colour changes are more subtle and can be difficult to determine. It was found that these reagent tests were not clear in the field, where the bright daylight masked the subtle colours. Testing indoors gave much more reliable results, especially when an empty sample pot containing the same

Table 4a: Complete species list for *Coenagrion pulchellum* breeding sites. The symbols in each cell relate to the hierarchy of recorded breeding status: AdM = adults recorded over multiple consecutive years; AdS = single adults only; Co = Copulation; Em = pre-flight emergent adults; Ex = exuvia; Ov = Oviposition. Sites: WPFL = Wicksteed Park Fishing Lake; ILRR = Irthlingborough Lakes, Ring Res; WWP = Weldon Woodland Park; BCPNL = Barnwell Country Park, North Lake.

Species	WPFL	ILRR	WWP	BCPNL
Calopteryx virgo	AdM			
Calopterxy splendens	AdM	AdM	AdM	AdM
Lestes sponsa	AdS		AdM	
Lestes dryas				
Chalcolestes viridis	Em	Em	Em	Ex
Platycnemis pennipes	AdS		AdM	
Pyrrhosoma nymphula	Ex	Ex	Ov	Ex
Ischnura elegans	Ex	Ex	Ex	Ex
Ennalagma cyathigerum	Ex	Ex	Ex	Ex
Coenagrion pulchellum	Ex	Ex	Ex	Ex
Coenagrion puella	Ex	Ex	Ex	Ex
Erythromma najas	Ex	Ex	Ex	Ex
Erythromma viridulum	Ex	Em	Em	Em
Brachytron pratense	Ex	Ex	Ov	Em
Aeshna isosceles	Em			
Aeshna grandis	Ex	Ex	Ex	Ex
Aeshna cyanea	AdM	AdM	Ex	AdM
Aeshna mixta	Ex	Ex	Ex	Ex
Aeshna affinis				
Anax imperator	Ex	Ex	Ex	Ex
Anax parthenope				
Cordulia aenea				AdS
Libellula depressa	AdS		AdS	AdS
Libellula fulva	AdS	Ex		Ex
Libellula quadrimaculata	Ex	Ex	Ex	Ex
Orthetrum cancellatum	Em	Ex	Em	Ex
Sympetrum striolatum	Ex	Ex	Em	Ex
Sympetrum sanguineum	Em	Ex	Em	Ex
Number of Breeding species	17	17	17	17

Table 4b: Complete species list for sites where *Coenagrion pulchellum* has not been recorded breeding. The symbols in each cell relate to the hierarchy of recorded breeding status using: AdM = adults recorded over multiple consecutive years; AdS = single adults only; Co = Copulation; Em = pre-flight emergent adults; Ex = exuvia; Ov = Oviposition. Sites: WPBL = Wicksteed Park Boating Lake; BCPMID = Barnwell Country Park Mid lake; BCPMILL = Barnwell Country Park, Mill Lake; ILDL = Irthlingborough Lakes, Dragonfly Lake; ILCR = Irthlingborough Lakes, Cotton Reel; DL = Ditchford Lakes; SLVCL = Stanwick Lakes, Visitor Centre Lake; SLTP = Summer Leys Toad Pond; FPP = Finedon Pocket Park.

Species	WPBL	BCPMID	BCPMILL	ILDL	ILCR	DL	SLVCL	SLTP	FPP
Calopteryx virgo	AdM								AdM
Calopteryx splendens	AdM	AdM	AdM	AdM	AdM	AdM	AdM	AdM	AdM
Lestes sponsa						AdM			
Lestes dryas									
Chalcolestes viridis			AdM	Em	Em	Ex	Em	Ex	Ex
Platycnemis pennipes						AdS			
Pyrrhosoma nymphula			Ex			AdS			Ov
Ischnura elegans	Ex	Ex	Ex	Ex	Ex	Ex	Ex	Ex	Ex
Ennalagma cyathigerum	Ex	Ex	Ex	Ex	Ex	Ex	Ex	Ex	Ex
Coenagrion pulchellum									
Coenagrion puella	Ex	Ex	Ex	Ex	Ex	Ex	Ex	Ex	Ex
Erythromma najas	Ex	Ex	Ex	Ex	Ex	Ex	Ex	Ex	
Erythromma viridulum	Ex	Em	Em	Em		Em	Em	Ex	Ex
Brachytron pratense	AdS	Em	Ex	AdM	Ex	Ex	Ex	Ov	AdM
Aeshna isosceles			AdS			AdS		AdM	
Aeshna grandis	AdM	Ex	Ex	Ex	Ex	Ex	Ex	Ov	Ex
Aeshna cyanea		AdM	Ex	AdM	AdM	AdM			Ov
Aeshna mixta	Ex	Ex	Ex	Ov	Ex	Ex	Ex	AdM	Ex
Aeshna affinis									AdM
Anax imperator	Ex	Ex	Ex	Ex	Ex	Ex	EX	Ex	Ex
Anax parthenope							Ov		
Cordulia aenea		AdS							
Libellula depressa				AdS		AdS			Ex
Libellula fulva		Ex	AdM		AdM	Ex	AdM	AdM	AdM
Libellula quadrimaculata	Ex	Ex	Ex	Ex	Ex	Ex	Ex	Ov	Ex
Orthetrum cancellatum	Em	Ex	Ex	Em	Ex	Ex	Em	Ov	AdM
Sympetrum striolatum	Ex	Ex	Ex	Em	Ex	Ex	Ex	Ex	Ex
Sympetrum sanguineum	Em	Ex	Ex	Em	Ex	Ex	Ex	Ex	Ex
Number of breeding species	11	14	15	13	13	15	15	13	14

Table 5a. Water quality results for sites with a breeding colony of Coenagrion pulchellum. Sites:WPFL = Wicksteed Park Fishing Lake; ILCR = Irthlingborough Lakes, Cotton Reel; WWP = Weldon Woodland Park; BCPNL = Barnwell Country Park, North Lake. N /D = Not Detectable.

Attribute	Tap Water	WPFL	ILRR	WWP	BCPNL
pH	7.6	7.8	7.6	7.2	8.4
Total alkalinity, ppm	180	180	120	80	180
Hardness, ppm	250	500	500	100	500
Nitrates, ppm	N/D	0.50	0.20	0.25	0.20
Sulphate, ppm	N/D	N/D	N/D	50	N/D
Carbonate, ppm	120	180	150	120	180
Dissolved Oxygen, ppm	8	12	12	12	12
Phosphate, ppm	N/D	0.25	0.5	0.05	0.15
Ammonia, ppm	N/D	N/D	N/D	N/D	N/D
Turbidity, NTU	0	<10	<10	<10	<10

Table 5b. Water quality results for sites where Coenagrion pulchellum has not been recorded breeding but are in close proximity to breeding sites. Sites: WPBL = Wicksteed Park Boating Lake; BCPMID = Barnwell Country Park Mid lake; BCPMILL = Barnwell Country Park, Mill Lake; ILDL = Irthlingborough Lakes, Dragonfly Lake; ILCR = Irthlingborough Lakes, Cotton Reel. N /D = Not Detectable.

Attribute	WPBL	BCPMID	BCPMILL	ILDL	ILCR
pH	7.8	7.6	7.8	7.6	7.6
Total alkalinity, ppm	180	120	180	180	120
Hardness, ppm	500	250	250	500	500
Nitrates, ppm	0.50	0.20	0.20	0.05	0.05
Sulphate, ppm	N/D	N/D	200	N/D	N/D
Carbonate, ppm	180	80	180	120	40
Dissolved Oxygen, ppm	6	6	4	12	12
Phosphate, ppm	0.10	0.25	0.50	10	5.0
Ammonia, ppm	N/D	N/D	N/D	N/D	N/D
Turbidity, NTU	<10	<10	<10	<10	<10

Table 5c. Water quality results for sites where Coenagrion pulchellum has not been recorded breeding but are visually similar to breeding sites. DL= Ditchford Lakes; SLVCL = Stanwick Lakes, Visitor Centre Lake; SLTP = Summer Leys Toad Pond, FPP = Finedon Pocket Park. N /D = Not Detectable.

Attribute	DL	SLVCL	SLTP	FPP
pH	7.2	7.4	7.6	8.4
Total alkalinity, ppm	120	120	120	240
Hardness, ppm	250	250	100	500
Nitrates, ppm	0.10	0.30	0.10	0.10
Sulphate, ppm	N/D	N/D	N/D	N/D
Carbonate, ppm	120	40	180	120
Dissolved Oxygen, ppm	12	12	12	6
Phosphate, ppm	0.15	0.15	0.30	1.50
Ammonia, ppm	N/D	N/D	N/D	N/D
Turbidity, NTU	<10	<10	<10	<10

Table 6. Results of the single-factor ANOVA on each variable. Values of >0.05 indicate no significant difference between the breeding and non-breeding sites.

Attribute	Proximity	Visual	Complete data set
pH	0.77	0.79	0.85
Total alkalinity, ppm	0.56	0.80	0.42
Hardness, ppm	1.00	0.37	0.85
Nitrates, ppm	0.46	0.17	0.17
Sulphate, ppm	N/A	N/A	N/A
Carbonate, ppm	0.30	0.23	0.21
Dissolved Oxygen, ppm	0.07	0.37	0.13
Phosphate, ppm	0.22	0.40	0.33
Ammonia, ppm	N/A	N/A	N/A

Table 7. Dominant aquatic vegetation at all test sites.

Site	*C. pulchellum* status	Main Aquatic Vegetation
Weldon Woodland Park	Breeding	*Nymphaea* sp. *Typha angustiflora* *Ceratophylum demersum*
Wicksteed Park Boating Lake	Proximity	*Ceratophylum demersum* *Typha angustiflora*
Wicksteed Park Fishing Lake	Breeding	*Sparganium erectum* *Ceratophylum demersum* *Typha latifola* *Nymphaea* sp.
Barnwell Country Park North Lake	Breeding	*Sparganium erectum* *Ceratophylum demersum* *Nymphaea* sp.
Barnwell Country Park Mid Lake	Proximity	*Sparganium erectum* *Elodea canadensis*
Barnwell Country Park Mill Lake	Proximity	*Ceratophylum demersum* *Typha angustiflora*
Irthlingborough Lakes Ring Res	Breeding	*Sparganium erectum* *Elodea canadensis*
Irthlingborough Lakes Dragonfly Lake	Proximity	*Sparganium erectum* *Elodea canadensis*
Irthlingborough Lakes Cotton Reel	Proximity	*Glyceria maxima* *Phragmites australis*
Ditchford Lakes	Visual similarity	*Sparganium erectum* *Ceratophylum demersum*
Finedon Pocket Park	Visual similarity	*Sparganium erectum* *Ceratophylum demersum*
Summer Leys Toad Pond	Visual similarity	*Ceratophylum demersum* *Sparganium erectum*
Stanwick Lakes Visitor Centre Lake	Visual similarity	*Ceratophylum demersum* *Sparganium erectum* *Typha latifola*

volume of water was used alongside the test pot to clearly show any visual colour differences, (Plate 2). For example, the Salifert reagent kit allows nitrate measurements of 0, 0.2, 0.5, 1, 2.5, 5, 10 ppm, which provided better resolution. Digital measurements will provide much more accurate and repeatable results and should be considered to fully investigate the above results.

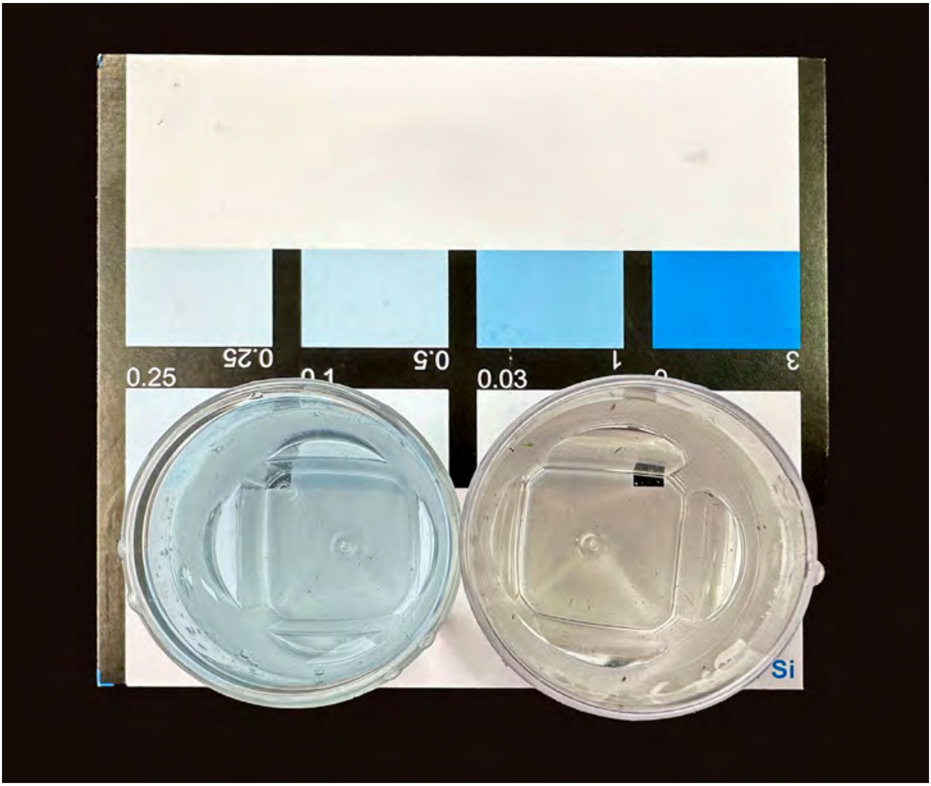

Plate 2. Reagent-based colour change using the Salifert Phosphate test kit. Test water is shown on the left after the addition of reagents; the same water before the addition of the reagents is shown on the right. This visual contrast helps determine the level of phosphate in the water.

Water Quality

The quality of the water in the lakes tested is classified as poor, due to nutrient enrichment, but also of high biological productivity for the same reason. The range of other species that breed in these lakes include *Libellula fulva* (Scarce Chaser) (at Irthlingborough Ring Res and Barnwell Country Park, North Lake), which is normally a flowing river species, indicating that they can support a wide range of species, as well as fish (all the lakes contain fish) and other invertebrates. The high oxygen levels in these static waters may allow *Libellula fulva* larvae to survive, despite the lack of flow. Species not breeding in these lakes, such as *Calopteryx virgo* (Beautiful Demoiselle) and *Lestes sponsa (Emerald Damselfly)*, are more specialist in habitat requirements.

Non-breeding sites in close proximity to breeding sites, such as at Irthlingborough

Lakes, share equally high oxygen levels, but at Barnwell Country Park, the two non-breeding lakes have significantly lower DO. Similarly, at Wicksteed Park, the non-breeding boating lake has significantly lower oxygen than the breeding lake. This might imply, all other things being equal, that *C.pulchellum* will choose a high DO site in preference to a low DO site in the same vicinity. However, when there are other high DO sites close by that are not used for breeding, we might conclude that high DO is an important factor, but it may not be the only criterion for site selection. For this to be true, *C. pulchellum* must be able to detect oxygen levels. In this case, the environment and in particular, emergent and submerged vegetation, may be as important.

High DO may be indicative of significant oxygenating aquatic plant life. All of the breeding lakes in this study have a very large surface area, but water depth could not safely be measured. In eutrophic waters like these, oxygen levels may decrease as summer progresses due to the growth of algal blooms (L.G. Sonic B.V, 2025), which consume water oxygen. Hence DO levels in late summer could be expected to be lower than in spring, when these measurements were made. If DO decreases enough, this will affect all aquatic life to varying degrees, such as killing fish when it drops below 2 mg/l (Reptile Knowledge, 2025). Water temperature also affects the saturation point for dissolved oxygen: at 7^{o} C the maximum amount of DO water can hold is 11.9 mg/l, while at 32^{o} C it is only 7.4 mg/l (University of Florida, 2025). This implies that shallower ponds, which warm up more quickly than deeper ones, naturally have lower DO later in the summer.

Silva *et.al*. (2010) suggested that the effects of water quality parameters are much less important than the surrounding landscape, at least for the species and environments in their study. However, their discussion indicated that differences in DO have statistically significant effects on populations.

For those breeding sites where there is a complex of other static water bodies that are non-breeding in close proximity (for example at Irthlingborough Lakes and Barnwell Country Park), none of the non-breeding lakes meet the criteria for visual similarity and high DO. There are other sites that do meet these criteria, though, such as Ditchford Lakes, so why does *C. pulchellum* not breed there? Is it because *C. pulchellum* has low dispersal tendencies and has not discovered these sites yet? It would be interesting to know the source of these colonies to understand more about dispersal in this species. It would seem feasible that the colonies at Irthlingborough and Wicksteed Park originate from Felmersham, which in turn may have expanded from those in the Huntingdon area (iRecord, 2025). The colonies at Barnwell and Weldon may have originated from those in the Peterborough area, these being the closest to these sites.

Observations of Ovipositing

The fishing lake at Wicksteed Park is very accessible, allowing good observation of adult reproductive activity in *Coenagrion pulchellum*. As part of regular recording, photographic records of ovipositing have been made since the colony was first discovered, which show clear differences in chosen substrate as the season progresses. These appear to be related to the growth of submerged and marginal vegetation. In early May, when vegetation growth is low, ovipositing pairs use the abundance of floating dead leaves of *Sparganium erectum* and dead stems of *Typha latifolia* (Plates 3A & B) that are trapped within the matrix of emergent plant growth close to the margins (Plate 4). As seasonal growth progresses, these areas fill in with vegetation, limiting ovipositing opportunities. In late June, as *Ceratophylum demersum* growth reaches the surface. *C. pulchellum* favour these areas (Plate 5A). However, as *S. erectum*, *T. latifolia* and *C. demersum* all occur at non-breeding sites this does not explain oviposition site selection on its own.

With the exception of Finedon Pocket Park, which is a large pond rather than a lake, the other visually similar sites share the same high DO as the breeding sites, so why are they not selected? One possibility is that they have not yet been been recorded, being obscured by the much larger populations of *Enallagma cyathigerum*, for example. At the four studied breeding sites, the populations vary significantly in size. Wicksteed Park Fishing Lake is the primary site with >100 adults recorded at peak season. The three other sites remain at low population levels, even several years after their first discovery. This may be linked to the extent of suitable ovipositing areas. Wicksteed Park has extensive areas of decaying *Sparganium erectum* (Plate 4) in early spring and a large growth of *Ceratophylum demersum* and *Nymphaea sp*. The other sites only have small, scattered areas of *S. erectum*, perhaps limiting the size of the *C. pulchellum* colony. Weldon Woodland Park has no *S. erectum* but very extensive *Nymphaea alba, N. marliacea,* and *Ceratophylum demersum* later in the season, and the colony remains low in number too. Similarly, Barnwell Country Park has scattered *S. erectum*, large areas of *Nymphaea sp.* and *Ceratophylum demersum.* The availability of good ovipositing areas in early spring seems, therefore, to be an important factor in the colony size.

Conclusions

This study shows that, in Northamptonshire, *Coenagrion pulchellum* favours eutrophic sites with high levels of dissolved oxygen and extensive areas of dead *Sparganium erectum, Typha latifolia, and Nymphaea sp.*. Growth of *Ceratophylum demersum* later in their breeding season is also an important

A

B

Plate 3. Tandem pairs of *Coenagrion pulchellum*, A) ovipositing into dead Sparganium erectum, 12 May 2025;. B) ovipositing into dead T*ypha latifolia*, 20 June 2025.

Plate 4: Prime habitat for oviposition by *Coenagrion pulchellum* at Wicksteed Park, with a matrix of *Sparganium erectum* with live plants and dead leaves at the lake margins, 18 May 2025.

factor when marginal growth of *S. erectum* has overwhelmed the dead leaves that are used as ovipositing substrates in the early spring. However, the species' absence from some sites with high DO implies that other factors contribute to a successful breeding site. Studies of the dispersal tendencies of *C. pulchellum* would also be useful to understand why high DO/visually similar sites are currently not occupied.

Apart from high levels of DO, water quality appears not to be a factor in site selection, other than as a predictor of a site with good aquatic vegetation.

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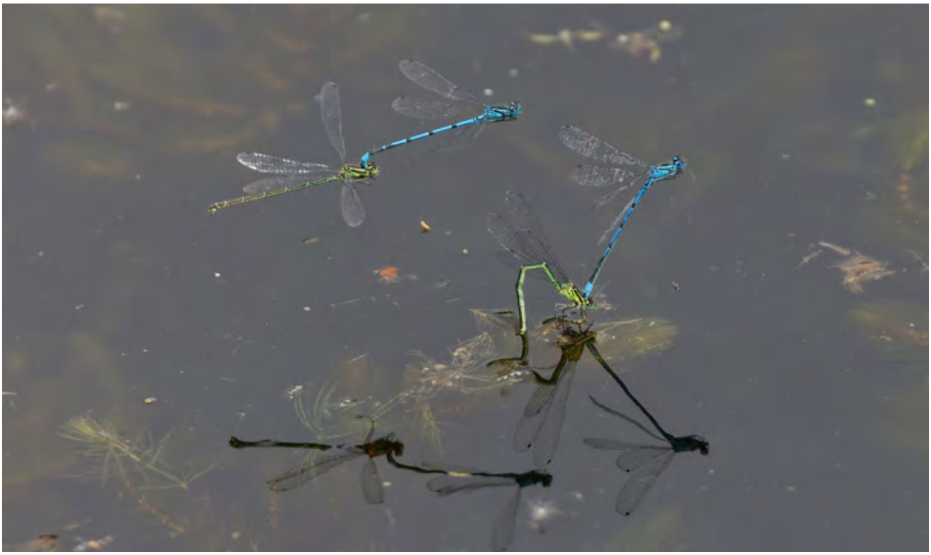
A



B

Plate 5: A) *Coenagrion pulchellum* ovipositing into *Ceratophylum demersum*, 20 June 2025. B) *Coenagrion puella* (Azure Damselfly) ovipositing into *Ceratophylum demersum*, 20 June 2025.

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