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

Articles for publication should be sent to the Editor. Instructions for authors appear inside the back cover.

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- Word processed manuscripts may be submitted in electronic form either on disk or by e-mail.
- Manuscripts should be one and a half spaced, on one side of the page only and with margins at least 25mm on both sides and top and bottom. Footnotes should be avoided.
- Use of these terms is acceptable: ‘exuvia’ for cast skin (plural: ‘exuviae’); ‘larva’ (instead of ‘naiad’ or ‘nymph’); ‘prolarva’ to designate the first larval instar.
- Dates in the text should be expressed in the form: 24 July 2010.
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- The legend for each table and illustration should allow its contents to be understood fully without reference to the text.

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

SCIENTIFIC AND ENGLISH NAMES OF BRITISH ODONATA

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

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

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Recent Observations of *Aeshna caerulea* (Azure Hawker) in Scotland

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Summary

The population of *Aeshna caerulea* (Azure Hawker) in Scotland has been inferred as undergoing a decline. However, many of the apparent gains and losses are likely to be attributable to recording effort.

This study revisits sites that have not been recorded from for 10 years or more and investigates other potential bog pools for breeding data through surveying for larvae.

Two important breeding populations were found in Glen Garry and above Loch Quoich, extending the known range. These could be part of a much larger complex in the whole area. Breeding pools were also found at Rannoch Moor and Corrour.

Recent surveys confirm the importance of higher-level upland blanket bog pools as the breeding habitat for this species. The lack of large larvae underlined the low productivity of the species and a large area may be needed to sustain the population.

An update is also given on the current situation for *A. caerulea* from other sources since 2012, which was the approximate cut-off date for data for the Atlas of British and Irish Dragonflies (Cham *et al*., 2014). The range of *A. caerulea* is expanding in the Highlands. However, after extensive survey work, it appears possible that the species may have been lost from its most southerly site. More survey work is needed to investigate other, older records and to locate breeding areas.

Introduction

Aeshna caerulea (Strőm) (Azure Hawker), has a boreal Paleartic distribution, occurring mainly above 55° latitude. Relict post-glacial populations are present

in the mountainous regions of Europe including Scotland. *Aeshna caerulea* is classified as vulnerable in the Red data list for Britain (Daguet, 2008). It is restricted to the Scottish Highlands, north and west Scotland, and there is a small population in Galloway.

Aeshna caerulea breeds in bog pools of various sizes. Through intensive sampling in the Loch Maree area, Smith *et al*., (2000) found the species favoured small shallow pools, 1-8 m², and with a water depth of 10-15cm. The emergent vegetation was sparse, mainly *Eriophorum sp.* (Cotton Grass). The substrate was of soft soupy detritus of varying depths (Clarke, 1994; Smith *et al*., 2000). The presence of *Sphagnum cuspidatum* (Peat Moss) with areas of open water was also a factor (Willet, 2013). These pools are often associated with bog pool complexes at a range of altitude from 20 metres at Loch Maree to 310-580m at Dundreggan (Willet, 2013).

Eggs laid in the spring/summer go into diapause and do not develop until the following year (Corbet & Brooks, 2008). This was confirmed by Smith *et al*. (2000), with eggs hatching in May, when early instar larvae were found. Larvae take three to four years to develop (Clarke, 1994; Smith *et al*., 2000). Smith *et al*., (2000) found large numbers of smaller larvae but few larger ones. Older larvae, which are the least numerous due to high mortality during the long period of larval development, might possibly seek different habitat from the younger stages or hide more. Adults are more often seen feeding in sheltered areas, along burns or in wooded areas, than at the breeding pools (Willet, 2013).

The population of *A. caerulea* has been inferred as undergoing a decline (Cham *et al*., 2014). However, due to difficulties in recording, the national trend is unclear. There are both apparent gains and losses. Many of these gains are most likely due to greater recording effort and some of the declines can be attributed to areas not revisited.

The aims of this study were:

- To investigate some of the sites with breeding records that had not been visited for ten years or more.
- To look for breeding pools at some sites where adults had been recorded.
- To survey potential habitat for new sites.

An update will also be in given on the current situation for *A. caerulea* from other sources post 2012.

Methods

Sampling for larvae is the only practical way to determine breeding for this species. A selection of pools was sampled in the three selected areas, concentrating on those with the most suitable habitat. A colander with a small mesh was used to catch larvae. This trapped small larvae but not very early instars. The length of each larva was measured as the distance from the top of the head, excluding the antennae, to the distal tip of the paraprocts. All other dragonfly larvae seen were recorded. Detailed grid references were taken of all pools containing *Aeshna caerulea* larvae using a hand-held GPS. Survey work for larvae is not as dependent on sun and warm temperatures as it is for adults.

Sites

1. The study concentrated on the Glen Garry/Loch Quoich area (Fig, 1). Glen Garry is west of Invergary and contains Loch Garry and Loch Quoich, two large hydro-lochs. There are remnants of Scots Pine woodland and plantations of various ages. On the north side, between Loch Garry and Loch Loyne, is a broad undulating ridge at 300 to 550m altitude which stretches for 14 km with plateaux and small pool systems. The western glen is wet, open hill ground with some flatter areas and it becomes steeper and more mountainous above Loch Quoich. Five areas were surveyed which provided just a sample of the potential habitat:

    a. The moor between Loch Garry and Loch Loyne (NH1804) at the eastern end near the A87. Larvae had been found here on four visits between 1999 and 2005.

    b. Tomdoun area, Allt na Slataich bog (NH1401). Adults had been recorded from the woodland near here in 2000.

    c. Loch Quoich North, Allt a Mhell ridge (NH0403). This site consists of a number of pools amongst peat hags on a ridge above Loch Quoich.

    d. Loch Quoich South (NH0600, NH0701, NH0702). The slopes south of the dam have a series of shelves at different levels. The lower shelf was relatively dry and the small burns running into the area were drying up in May. Above this are pool complexes amongst R*hacomitrium* (mosses in the family Grimmiaceae) heath, similar to the Loch Maree sites (Smith *et al*., 2000).

Figure 1. The Glen Garry/Loch Quoich area to show the location of the seven sites that were sampled.

e. Small pools on the Gairich ridge (NN0599) were also sampled.

Visits were made on 15-18 May 2018 in good weather conditions, with temperatures 17-20°C and mostly with good spells of sunshine. The water felt warm on the surface. One to three hours were spent at each site.

2. Brief visits were also made to Rannoch Moor and to Corrour, with mostly between one and three hours spent at each site.

Corrour is at the eastern edge of Rannoch Moor and is isolated but can be reached by train. The site (NN366668) was visited on 30 September 2017. The weather was cool and the pools were full after a wet period and the water was cold.

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A small area of west Rannoch Moor (NN34) was visited on 11 May 2018, including three of the breeding sites found in 1998. After a cool start the temperature improved but cloud and rain came later in the day. The three sites were:

a. Loch Ba bridge west (NN307495), which is close to the A82 just north of the bridge.

b. An Torr NNE (NN305458).

c. Bridge of Orchy pool (NN294411).

Results

Glen Garry / Loch Quoich

Habitat All five sites were in blanket bog at an altitude varying from 163m to 445m at Allt a Mhell ridge. The vegetation in the pools was sparse, mainly *Eriophorum angustifolium* (Cotton Grass) and *Sphagnum cuspidatum* (Peat Moss). *Aeshna caerulea* larvae were most often found in open water or in areas with sparse cover in pools. The pools varied in size from 0.5 x 0.5m and 10-15cm deep to 20 x 15m and 20-30cm deep. Most larvae were found in pools 1m wide, up to 10 m long and 20-30cm deep. Many of the pools were linked with runnels or depressions that would hold water during wet weather. On the lower sites there was a preponderance of ribbon-like pools in old river courses, with areas of dense S*phagnum sp.* The substrate was olive brown silt from decaying S*phagnum. Aeshna caerulea* larvae were not found in pools with areas of bare peat.

Larvae The numbers of pools and larvae found are summarised in Table 1. Pools without *Aeshna caerulea* larvae have not been included. The moor between Loch Quoich and Loch Garry was the most productive site with 57 larvae in four pools. Larvae have been consistently found at this site since 1999.

The Loch Quoich area had not been surveyed before; hence all sites are new and in three new hectads. The Loch Quoich South dam area had 74 larvae in total from the three levels. Most were found at the upper level but fewer pools were sampled in the mid area and it merits more investigation. The other sites were in poorer habitat. Gairich Ridge NN0599 was an outlying, atypical site with few pools. Possibly the one *A. caerulea* larva found here was because of its proximity to the larger site on the ridge below. Loch Quoich North Allt a Mhell ridge had a preponderance of peaty pools and three larvae were found in two pools at the edge of the complex. The Allt na Slataich bog held only four larvae. Again, these were in four less typical pools that were choked with S*phagnum spp.* Though few larvae were found, adults were seen in the nearby Tomdoun woodland on three occasions between 7 and 29 June 2018, with two females

Table I. Summary of the numbers of *Aeshna caerulea* larvae found in pools in the Glen Garry/Loch Quoich, Rannoch Moor and Corrour Areas.

Site Name	Date	Alt. a.s.l.	Grid Ref.	No. of Larvae	No. of pools with *larvae*
Moor between Loch Garry and Loch Loyne	15/05/2018	330 m	NH1804	57	4
Tomdoun W Allt na Slataich bog	16/05/2018	188 m	NH1401	4	3
Loch Quoich North Allt a Mhell ridge	16/05/2018	445 m	NH0403	3	2
Loch Quoich South dam upper pools	17/05/2018	260 m	NH0600	49	10
Loch Quoich South dam mid pools	16/05/2018	242 m	NH0701	11	4
Loch Quoich South dam lower pools	16/05/2018	163 m	NH0702	14	4
Loch Quioch SE Gairich ridge	16/05/2018	367 m	NN0599	1	1
			Total	139	28
Corrour track NW	30/09/2017	408 m	NN366668	2	1
Rannoch Moor Loch Ba bridge west	11/05/2018	305 m	NN307495	2	1
Rannoch Moor An Torr	11/05/2018	300m	NN305458	3	1

and five males being recorded on 7 June (BDS Data Base, 2018). These could be breeding in higher level pools that were not investigated.

Larval sizes Full measurements were noted at all sites except for the moor between Loch Loyne and Loch Garry, where the larvae were recorded in size classes. Of the 57 larvae found here only one was 27mm long, the rest were between 10 and 20 mm. At all sites only 11 of the 139 larvae were over 20mm long. All of the larvae found here, together with those found at Rannoch Moor and Corrour, were plotted in size classes (Fig. 2)

For the sites where individual measurements were made, the majority of larvae were also between 10 and 20 mm long. The number of larvae found decreases as the larvae get bigger, indicating a high mortality rate. Details of individual larval sizes for these sites are shown in Figure 3. From detailed work and captive rearing (Smith *et al*., 2000; Clarke, 2002), the lengths ascribed to larvae in different years have been estimated as:

5-18mm	1st year larvae
19-27 mm	2nd year larvae
28-39 mm	3rd year larvae.

This is an estimate as growth rates vary depending on food availability. As the sites are at a higher altitude than those nearer sea level at Loch Maree it is feasible the growth rate would be slower.

The smallest larvae recorded were 9 – 11mm long, the minimum size for overwintering (Smith *et al*., 2000). As eggs do not hatch until the following year (Corbet & Brooks, 2008) they would be one year old, hatched from eggs laid in 2016 and may not emerge until 2020 or 2021. The three larvae at 27mm were from the deeper pools and could be 2 or 3 years old. Larvae are fully grown at between 34 and 39mm (Willet, 2013). Only one larva was likely to emerge in 2018 at 33mm long with wing buds reaching the third segment (indicating stage F-1). It was found in a small pool, 1 x 1 m long 20 cm deep, at the Loch Quoich Dam South Mid pools.

Larvae of Other Dragonfly Species The most common species found in pools alongside *Aeshna caerulea* was *Libellula quadrimaculata* (Four-spotted Chaser) which was found in 18 of the 27 pools (66%). *Aeshna juncea* (Common Hawker) was found in 12 pools (44%); many of these larvae were small, about the same size as those of *A. caerulea.* The surrounding pools without *A. caerulea* contained many more *A. juncea* larvae. *Leucorrhinia dubia* (White-faced Darter) was found in two larger pools and S*omatochlora artica* (Northern Emerald) in linear pools amongst more dense S*phagnum*.

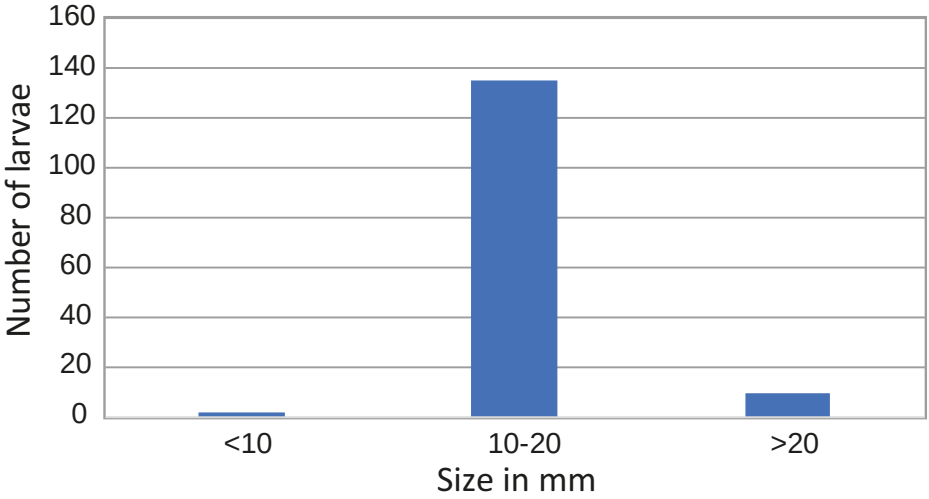

Figure 2. The length distributions in size classes of all the *Aeshna caerulea* larvae found at Glen Garry/Loch Quoich and Rannoch Moor in May 2018 and at Corrour in September 2017. n = 146.

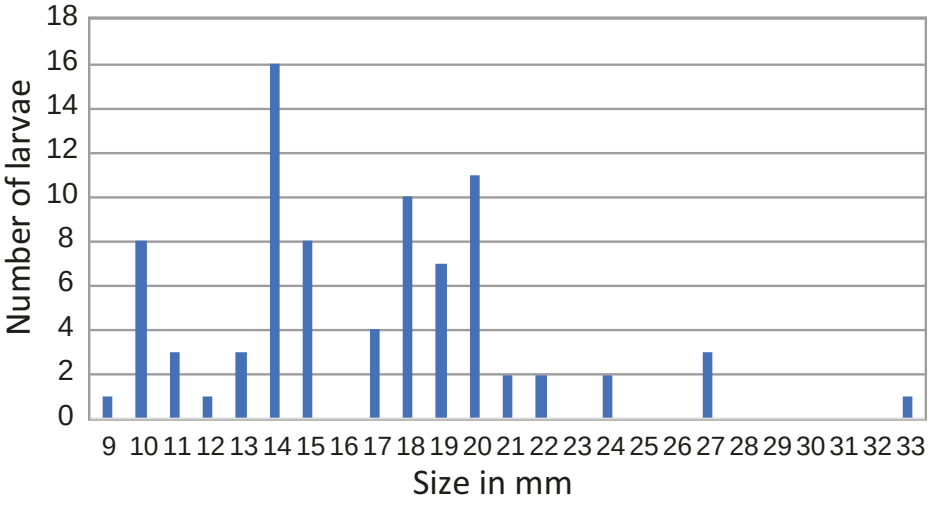

Figure 3. The length distributions of those *Aeshna caerulea* larvae found in the Glen Garry/Loch Quoich area (excluding the site on the moor between Loch Loyne and Loch Garry) on 16-17 May 2018. n = 82.

Rannoch Moor and Corrour areas

Habitat Rannoch Moor, in which Corrour lies, comprises a huge expanse of blanket bog with numerous pools that stretches across Rannoch Moor for 20 km.

Larvae At Corrour a full day by two people was spent on the survey. Despite the concentrated effort only two small *Aeshna caerulea* larvae, measuring 7mm and 10mm, were found. The pool was in the same area where *A. caerulea* larvae had previously been found in 1997. There have been occasional sightings of adults from Corrour to Loch Ossian between 1992 and 2012 (BDS Data Base, 2018) and 1-5 larvae were found in three pools in the general area in 2004.

In the sites on the west of Rannoch Moor, two *A. caerulea* larvae of length 19 mm were found in a linear pool at Loch Ba bridge west (Table 1). Over 20 larvae were found in 1998 when the pools were warmer and more people were searching. In 2008 at An Torr NNE, three larvae 16mm long were found in a small linear pool. The Bridge of Orchy pool, is a well-known site for *Leucorrhinia dubia.* No *A. caerulea* larvae were found here in 2018. One to two larvae were found in the shallower arms of the pool in 1998 and 2002 and an adult was seen in 2004. The site was surveyed for larvae on several occasions, between 2005 and 2017 and *A. caerulea* was not found on any of these.

Other Surveys from BDS Records

There are eight main areas that have been surveyed in Scotland (Fig. 4).

Glen Moriston to Glen Affric

There is a large area of remote hill ground which stretches for over 20km between Glen Moriston and Glen Affric (NH12, NH21, NH22, NH31, NH32, NH33). The pools here above Dundreggan were found to be an excellent site for *Aeshna caerulea* in 2010-2011 (Willet, 2013). The sizes of larvae measured in October 2011 by Willet (BDS Data Base, 2018) (Fig. 5) follow a similar pattern to those recorded in Glen Garry in May 2018. Smith et al., (2000) found there was little growth, approximately 1mm, over winter. The June/July 2011 sample had more smaller larvae, less than10mm in length, and limited numbers of larger larvae (BDS Data Base, 2018).

Colin Hall and a team of volunteers surveyed different parts of this remote area in 2015, 2016 and 2017. Over the three years, in total 26 pools contained *A. caerulea*, with 1-2 larvae found in each pool. With additional survey work the breeding area was found to be more extensive. The pools were at 360-785m

Figure 4. The location of the eight main survey areas in Scotland.

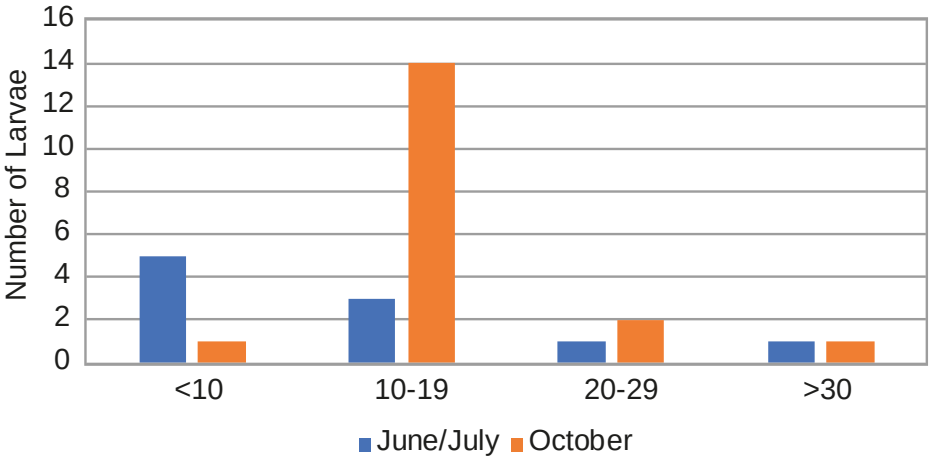

Figure 5. Length distributions in size classes (in mm) of *Aeshna caerulea* larvae from pools at Dundreggan by Jonathan Willet in 2011. n = 28. Data reproduced with permission of J. Willet.

altitude on Carn Glas Lochdarach (NH162201), much higher than has been recorded previously in Scotland. Breeding pools were also found on the north side of Loch Affric (BDS Data Base, 2018).

Since publication of the atlas (Cham *et al*., 2014), a small number of adults have been recorded in the pine woodlands of Glen Affric and Glen Cannich and they have also been recorded at Dundreggan, mainly along the sheltered burns. One pair in cop was seen in Glen Affric on 24 June 2018.

Loch Maree Area

Peter Vandome has visited Grudie Bog (NG967680) and the Silver Pools (NG9370) annually for 1-3 weeks from 2014 to 2018. He was surveying the pools for emergence of *Aeshna caerulea.* Despite intensive searching over several days at the right time each year he only witnessed emergence on 20 May 2014 and 10 June 2015. He found one exuvia on 30 May 2016 but no others in any of the years even though emergence had taken place. Some large larvae, five in 2014 (27-30 mm long) and one on 23 May 2016 (34-35mm long), close to emergence were recorded. Adults were flying by 30 May 2018. A female was ovipositing at Silver Pools on 25 July 2014. The only other recent record for egg laying was at Grudie bog on 19 July 2013 (BDS Data Base, 2018)

The Loch Maree/Torridon area has the most adult sightings; this is not surprising as it is the area most often visited. However, only small numbers are ever seen in this area at any one time, 2018 being the exception with at least eight seen across three sites. (Vandome pers. comm.)

Galloway sites

The last recorded sighting of *Aeshna caerulea* in southern Scotland at Silver Flowe was 30 May 2016 when one larva, 18 mm long, was found in the Merrick area (NX476823), the first seen since 2003. Adults have not been recorded since 2014 (BDS Data Base, 2018). Despite intensive survey work in 2017 and 2018 looking for adults and larvae in good conditions the species was not found (Clarke, Merritt & Mearns, pers. comm.)

Forsinard

No *Aeshna caerulea* larvae were found at Forsinard (NC960457) in Sutherland. Known pools were searched on 2-4 October 2018 (Hudspeth & Muir pers. comm.). The pools were in poor conditions after the summer drought and further survey work is needed here. Larvae were recorded in 1994 and 1996 (Smith *et al*., 2000).

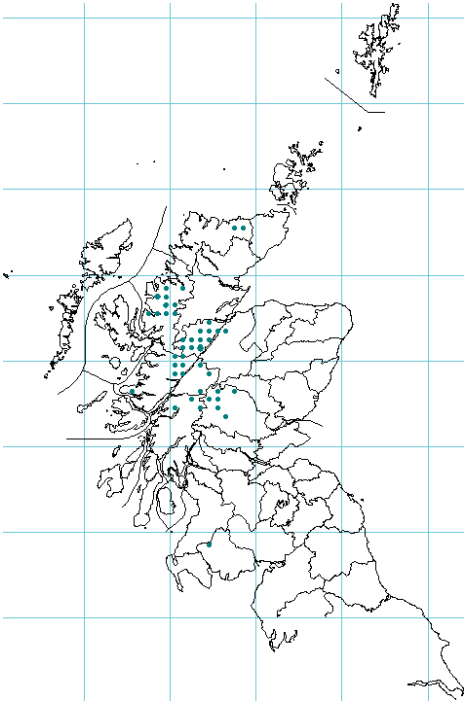

Figure 6. The distribution of *Aeshna caerulea* in Scotland from 2013-2018. Aditsite Map using records from the BDS Data Base (2018).

General records

Since the Atlas (Cham *et al*., 2014), *Aeshna caerulea* has been seen in 44 hectads in Scotland (Fig. 5). Of these, 14 are new hectads for the species, six have updated records for recent loss and three for old loss. This reflects the increased recorder effort.

Many of the records are chance sighting of single males, including one drowned in Loch Broom. There have been recent records from historical sites in Perthshire. Adults have been recorded from a number of areas in Lochaber and from Glen Affric north to Inverness, with at least two new breeding sites. There has been little recent recording in Caithness and Sutherland, or on Skye and Rhum. There are a number of pre-2000 sites in these areas.

Discussion

Loch Quoich/Glen Garry

The pools where *Aeshna caerulea* larvae were found were similar to those described elsewhere (Clarke, 1994, Willet, 2013). Most were 20-30 cm deep and few were as shallow as many of the Loch Maree pools (Smith *et al*., 2000). The number of larvae found was the largest since the intensive study at Loch Maree (Smith *et al*., 2000). The study coincided with a first period of warm weather in the spring and the larvae were active and feeding in the warm surface water after winter dormancy.

The lack of larger larvae has been noted in other studies (Clarke, 1994; Smith *et al*., 2000; Willet, 2013). Only one larva above 30mm was found in the current study and of the 139 larvae measured only 11 were above 20mm. Similarly, only one larva over 30mm was found at Dundreggan in both May and October (Fig. 5). Although mature larvae could be elsewhere, the level of survey effort indicates a high mortality rate.

It is unlikely that emergence would already have taken place, as spring 2018 had been particularly cold and these sites are at a high altitude. At Loch Maree, a lower site, the earliest emergence recorded was 19 May (Smith *et al*., 2000). Interestingly, although no mature larvae were found in the pools searched near Tomdoun in May, five adults were seen in the nearby woodland in June 2018, indicating a wider breeding area.

Pools had started to dry up in mid-May 2018 at the start of the dry period, which continued until mid-July. Many pools would have become dry by the end of this period, as noted elsewhere in Scotland. The bigger pools had deeper areas to provide a refuge but the smaller pools were likely to have been completely dry. The drought in August 1995 reduced the population in the Loch Maree pools by 60% (Smith *et al*., 2000), and none of the smaller larvae in that study survived. Many pools dried out and the water temperature in one pool reached 31°c.

The substrate of many pools is an olive brown silt which forms a crust when it dries, possibly leaving damp areas below. Larvae, including aeshnid larvae, can survive for short periods in dried up pools providing they can find a humid niche (Corbet, 1999). *Aeshna caerulea* was not found in pools with a bare peat base. This is solid and forms deep cracks when dry.

It is not unusual to have a dry spell in the Highlands in spring (Met Office, 2018). However, in recent years the weather has been more erratic. *Aeshna caerulea* has managed to survive over the years but is very vulnerable to prolonged

periods of extreme drought and this may be why populations are small (Smith *et al*., 2000).

Dry sunny weather, however, also provides many more days for surviving adults to be active and to lay eggs in any pools that remain. Conversely, after a dry early spring in 2017, the weather was very wet throughout the summer; thus water should have been plentiful in the pools for early larval development. This may have had a bearing on the larger number of small larvae seen.

Smith *et al*. (2000) speculated that *A. caerulea* was found in shallow water to limit the competition with *Aeshna juncea*. In this study 44% of the pools had *A. juncea* larvae, and many of those were small larvae. Only four pools had no other dragonfly larvae and two of these held the largest larvae of *A. caerulea* but numbers are too small to draw any conclusions. Other predators present in the larger pools included newts and great diving beetle larvae. When water levels reduce, larvae are more vulnerable to predation (Corbet, 1999).

The moor between Loch Loyne and Loch Garry has proved to be a well-established site. However, only a small number of pools in the area were sampled. The Loch Quoich area was selected by chance and a large new breeding area was found, though no pools were marked on the map. From the topography there are many other similar areas in the 13 km between the two sites. There are older records for *A. caerulea* both of breeding and for adults south of Loch Garry; these pools were not investigated. The whole area could be part of an extensive breeding complex.

Rannoch Moor and Corrour areas

Few larvae were found at Rannoch Moor and Corrour but the water in the pools on both visits was cold and not conducive for finding larvae. The fact that larvae were present after a gap of 20 and 13 years respectively, indicates that both sites are viable. It would be impossible to survey the whole area of Rannoch Moor because of its size and accessibility but more survey work is needed in selected areas.

Other Sites

Loch Maree/Glen Torridon in Wester Ross is a stronghold for this species. This area is also the most visited, so there is likely to be more records.

From recent BDS records (BDS Data Base, 2018) the breeding pools on the upland ground between Glen Affric and Glen Moriston cover a more extensive area than was originally known (Willet, 2013), now extending north to Glen

Affric. This area is above the pine woodland where most adults are seen. No breeding sites have yet been found in bogs in the woodland. *Aeshna caerulea* larvae have now been found up to an altitude of 785m in Scotland. Blanket bogs with small pools provide the main breeding habitat for the species in the Highlands.

Recent records have extended the known range of *A. caerulea* and given an update to some areas where the 'apparent' decline was due to lack of recording. Many records were of adults, often single males, from various parts of the Highlands. This indicates that this species could be more widespread than was previously thought. We have no idea how far adults disperse from breeding pools. The distribution maps (Cham *et al*., 2014) can give a misleading impression, however. Nowhere does the species seem plentiful. From all records collected since 2000 there have been only six records for ovipositing and seven for exuviae, mostly from the Loch Maree area.

On the negative side there have been no recent records from Speyside, which is a well visited area. There were a number of sightings pre-1960 and the last record was from 1988. A survey at Forsinard in 2018 failed to find any larvae in known breeding pools but more survey work is needed here.

Despite extensive surveys in 2017 and 2018 there have been no records from Silver Flowe in Galloway since 2016. This isolated population in Southern Scotland could be lost.

Conclusions

The Glen Garry/Loch Quoich area is important for *Aeshna caerulea*, with large numbers of larvae found at two sites. New breeding sites were found in three hectads. Given the amount of suitable, unsurveyed habitat in the area, this could be part of a much larger complex. Some breeding evidence was found at Rannoch Moor and Corrour after a recording gap of over 13 years.

The study underlined the low productivity of the species and a large area may be needed to sustain the population.

This survey work has emphasised the importance of high-level bog pools as a breeding habitat. They provide the main breeding area in Glen Garry/Loch Quoich and in Glen Affric and other sites.

Records since the Atlas (Cham *et al*., 2014) indicate that the species is more widespread in the Highlands than was originally thought. However, after

extensive survey work, it is possible that the species may have been lost from its most southerly site. Far more survey work is needed in all areas, particularly to obtain breeding information.

Acknowledgements

I would like to thank Andrea Hudspeth, BDS Scottish Officer, for creating the maps and for her help and that of Daniele Muir with survey work, including finding *Aeshna caerulea* larvae; Colin Hall, Peter Vandome and Jonathan Willet for access to their survey data and support and Barbara & Richard Mearns, David Clarke and Bob Merritt for information about work in Galloway. Also, thanks to Larry Templeton, Andy Scott and Margaret Currie, Jon & Angela Mercer for sending in records and many others who have contributed to the database. Last of all for the support and patience of Dave Batty who helped with this report and recording work.

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Coenagrion mercuriale (Southern Damselfly) at Povington, Isle of Purbeck, Dorset

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Summary

Coenagrion mercuriale (Charpentier, 1840) (Southern Damselfly) is found very locally in Southern Britain where it breeds in base rich, slow flowing streams and mires; its two year larval life cycle in the UK requires permanent waters. On the Isle of Purbeck, Dorset, *C. mercuriale* has been found in six sites, only one of which (Harland Moor) is currently thriving. One of the sites, at Povington, which is on MOD land, was discovered in May 1992, and in 1995 the colony was thought to comprise approximately 1500 adults and was the most important in Purbeck. Since that time the colony has declined and in 2016 only one adult was seen. This was the last sighting of this species at Povington.

On behalf of the British Dragonfly Society (BDS), the author undertook a study of the habitat to investigate the decline. In summary:

- The colony at Povington came about as a result of changing water flows associated with clay workings, probably in the 1980s.
- In 1996 it was proposed that the water flows would be diverted entirely away from the site.
- Following negotiations, a compromise solution was made, allowing some water to continue to flow through the site. Unfortunately, this compromise has provided insufficient water to maintain the colony.
- Although the water flow has improved, the reduced grazing of the area has led much of the habitat to become overgrown.
- The problems with water flow and grazing mean that it is unlikely that *C. mercuriale* survives at Povington.

Introduction

Coenagrion mercuriale (Charpentier, 1840) (Southern Damselfly) is one of the UK's rarest insects (Cham *et al*., 2014):

- Listed as "Near Threatened" in the European Red List.
- Listed as "Endangered" in the British Red List.
- One of only three dragonflies/damselflies listed in the UK Biodiversity Action Plan (BAP) as a Priority species.

In the UK, *C. mercuriale* is found in three different habitat types: heathland, chalk streams and calcareous fens; it is restricted to southern Britain. It is endemic to the Western Palearctic and, in the UK, it has a two year larval life cycle and, therefore, requires permanent waters (Cham *et al*., 2014).

Coenagrion mercuriale (Southern Damselfly) in Purbeck

The Isle of Purbeck (Fig 1) is a peninsula on the Dorset coast bordered by the River Frome and Poole harbour to the north and the English Channel to the south. An examination of the geology provides an explanation as to the suitability of the habitats for *Coenagrion mercuriale*. The streams which flow to the north are base rich as a result of the band of chalk which crosses the entire peninsula. The base rich streams flowing across the heathland on the sandstone of the Bagshot beds provide ideal habitat for *C. mercuriale*.

A significant geological feature of Purbeck, from a human viewpoint, is the presence of Ball Clay deposits (Fig 1). This is an important material in the manufacture of porcelain and, particularly, sanitary ware (Legg, 2014). The mining of the clay has had an enormous influence on the Purbeck landscape which, until relatively recently, was quite different from what we see today. Open cast mining dominated with a network of narrow gauge railways (Fig 1, Plate 1) whilst the remaining heathland was heavily grazed and managed for agriculture.

In this industrial environment *C. mercuriale*, whose probable range is fairly limited (Fig 1), thrived, with new habitats being provided by the mining, and by the streams being maintained by grazing and as agricultural boundaries.

In recent years, the clay mining has been greatly reduced, the industrial railways have disappeared (Legg, 2014), as has much of the agriculture. Tourism is now the main industry. Reduced grazing has led to neglect of the streams which have become overgrown and unsuitable for *C. mercuriale*. Currently, of the six known sites only one (Hartland Moor some 6 km from Povington) has a thriving population. This site is maintained by the National Trust by its provision

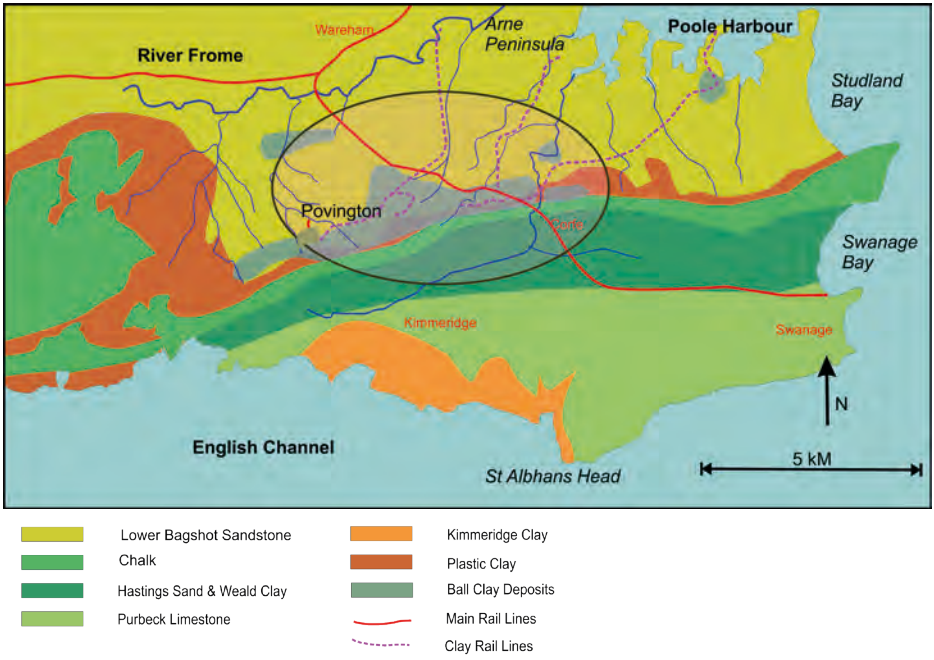


Figure 1. The geology of the Isle of Purbeck, showing the range of *Coenagrion mercuriale* in the region (oval outline). The Povington mires are shown in red and the clay pit to the south of it in grey at the bottom left of the oval.

of continued grazing (Dieck, in press).

Coenagrion mercuriale at Povington

The study area, known generically as Povington (Fig 1), is a large area of heathland. It is poorly studied ecologically and is used by the MOD as a training ground. Povington Heath was described by Ratcliffe (1977) as taking the form of "…a shallow bowl with a wet inner centre containing damp heath." He mentioned "several good ponds" and that *Ceriagrion tenellum* (Small Red Damselfly) was present. In May 1992 a thriving colony of *Coenagrion mercuriale* was discovered by Col. E.D.V.Prendergast which, following detailed monitoring, was thought in 1995 to be the largest colony on Purbeck (Prendergast, 1996). Unfortunately, since the late 1990s the population has been gradually declining. In July 2014 Robert Aquilina, a local ecologist, discovered that the Mires were dry and failed to find any adults (Aquilina, 2014). The British Dragonfly Society (BDS) was contacted at this time and the author embarked upon a study. In summary, since 2014 and despite intensive searching, only one male has been found (in 2016) and *C. mercuriale* is thought to be extinct at Povington. This paper examines the reasons for the decline and possible extinction at this site.

Observations

The Povington Mires and their changing water supply

The area of Povington, which provided habitat for *Coenagrion mercuriale*, consisted of two 'mires' known as Orchard Cottage Mire and Outflow Mire (Fig 2). To the south of these mires is a clay mine, which was originally underground. However, in the early 1970s, opencast operations commenced, forming the claypit (Prendergast, 1996). The extraction of the ballclay involves the removal of huge quantities of material that cannot be used. In summary, the pit was excavated and subsequently backfilled, migrating the workings at Povington in an easterly direction. The claypit was, from the 1970s, managed by English China Clays plc. In the late 1990s it was taken over by IMERYS (The Operator), which is a French based multi-national company.

The claypit has an enormous influence on the mires to the north as it interrupts the natural flow of water from the Purbeck Hills. The Operator has, therefore, to deal with both the water from the hills and that which derives from the excavations. This water is discharged to the north and it is the changes to this water management as the claypit moves eastwards that have had an enormous impact upon Povington. The changes to the water management are summarised below:

Pre 1985 (Fig 2) - The Mires were fed by an intermittent supply from the underground clay mine, which dried up during the summer months (A on Fig 2). The permanent stream at the bottom of the valley is shown as B on Fig 2. Outflow Mire would probably only have existed during periods of heavy rainfall. Orchard Cottage Mire was fed by springs and, as it was the lowest point of the heath, would probably have been a shallow mire. The only notable damselfly in the area was *Ceriagrion tenellum* (Ratcliffe, 1977).

1985 – 1995 (Fig 3A) - In the early 1980s the opencast operations were expanded eastwards. Settling ponds were installed by the Operator, which then discharged all water from the excavations into the Mires. This new increased and permanent flow transformed the habitat: Orchard Cottage Mire would have had a regular flow and Outflow Mire would be a permanent habitat. In addition, the area was grazed by up to 500 cattle, many of which entered the mires, controlling the vegetation and poaching the ground. This combination of factors, together with vegetation in both mires dominated by *Molinia caerulea* (Purple Moor-grass), *Juncus* spp. (rushes), and with *Potamogeton polygonifolius* (Bog Pondweed) and *Hypericum elodes* (Marsh St John's-wort) in the slow water courses (Winsland 1994), provided excellent conditions for *C. mercuriale*.

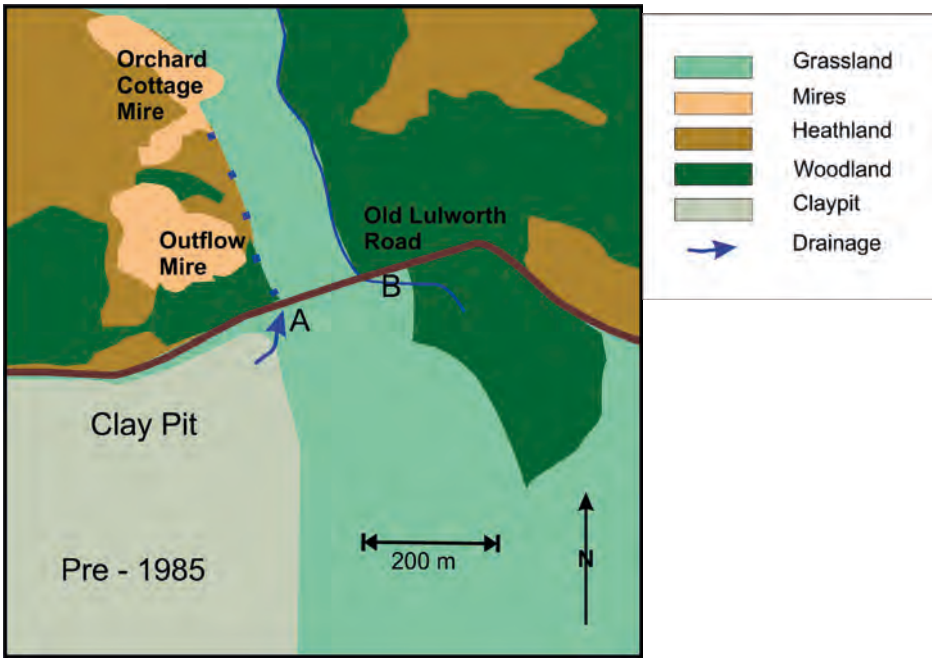


Figure 2. The Povington mires and their water supply pre 1985. A, intermittent supply from the underground clay mine which dried up during the summer months; B, the permanent stream at the bottom of the valley.

Plate 1. Open clay pit excavation at Newton in 1910. From Legg (2014).

As mentioned above, in May 1992 *C. mercuriale* was thriving at this site and, in 1995, was probably the largest colony on Purbeck (Prendergast, 1996). Prendergast even suggested that the flooding of the mires in this manner "… might well serve as a model for creating new habitats for the species". Thus the commercial operations of the Operator had created arguably the best habitat for *C. mercuriale* in Purbeck. For comparison, in early summer 2016, the author discovered in Cazorla Park in southern Spain, a sloping mire similar to the conditions that must have prevailed at Outflow Mire, i.e. a gentle flow passing through the vegetation, with a thriving colony of *C. mercuriale* (Plates 2,3).

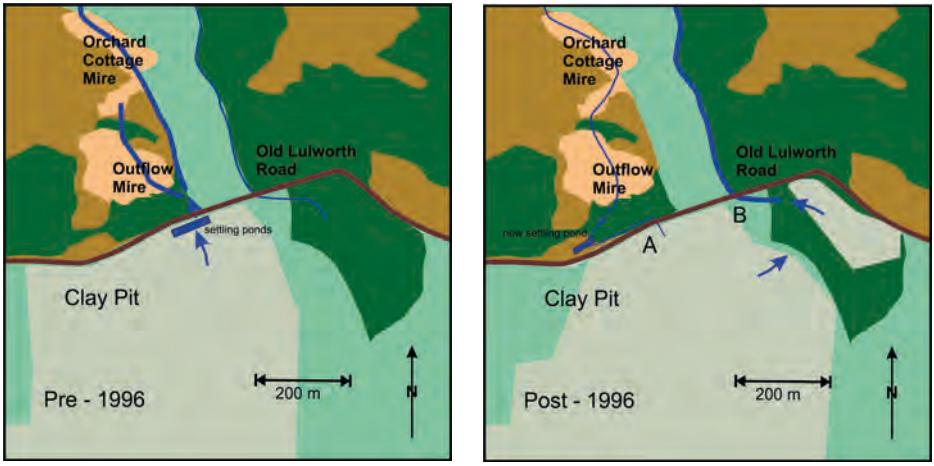
1996 to the present day (Fig 3B) By 1995 the Claypit had migrated further east and the settling lagoons needed to be resited. The initial proposal from the Operator would have removed all flows to the Mires. Prendergast (1996) entered into negotiations with the Operator and, as a result, a compromise solution was agreed whereby a new, albeit smaller, settling lagoon would be constructed to the north of the Old Lulworth Road and would provide water to the Mires from a different entry point directly into Outflow Mire. It was hoped that this compromise would maintain the colony (Prendergast, 1996).

In 1994 Winsland had carried out a survey of the mires, producing a map showing the extent of permanent wet habitat (Winsland, 1994). Since then there appears to have been a gradual drying of the mires. Attempts were even made to hold back water, particularly in Outflow Mire, by installing heather bales at strategic points (Plate 4). It is unlikely that this would have had any effect on the pH of the water as heather is dominant in the surrounding heath.

Since the mid 1990s, the population of *C. mercuriale* has suffered a gradual decline, culminating in its virtual extinction by 2014 (Table 1). As noted above, in July 2014 Aquilina (2014) discovered that Povington was dry and recorded no adults. Pump failure was blamed but did this explain the dryness of the habitat?

Following Aquilina's findings, it was agreed by all interested parties that a detailed survey of the area was required. On behalf of the BDS the author agreed to carry out the survey which, for operational reasons, was not commenced until 2016 when permissions were given for access. Two meetings were held with IMERYS and, in total, six site visits were made in 2016 and a further one in 2018

In July 2016 the author observed that there was no water flowing into the Mires, which were essentially dry. This was backed up by Footprint Ecology during their survey of *C. mercuriale* sites in Purbeck in 2016, where they described Orchard Cottage Mire as "…more closely related to Purple Moor Grass pasture than valley mire." (Panter *et al*., 2016). It would appear that the compromise



A B

Figure 3. The Povington mires and their water supply. A, 1985-1995; B, post 1996. See Fig. 2 for the key

solution for keeping the mires wet was not working. To understand the problems the following measurements were carried out (Chelmick, 2017):

- The total volume of water generated by the claypit which would up until 1996 have passed through the mires.
- The volume of water passing through the mires since 1996.

The estimates of water volume and flow were taken using:

- Vee notch flow measuring units installed in the streams by the Operator.
- For smaller outflows, a 10 litre bucket and stop watch (Plate 5).

The author has discussed the overall flows with the Operator who has agreed that they are generally in accord with their own records. The author also discussed with The Operator whether there was any significant seasonal variation in flows. The Operator confirmed that there was no significant difference throughout the year and that the total volumes of water would not have varied over the years.

In summary, the total flow of water from the workings since 1985 is approximately 75 m^3/hr. Up until 1996, this entire flow passed through the mires (Fig 3A). Since 1996 the compromise solution (Prendergast, 1996) has meant that the flow north has been in two parts (Fig 3B):

Plate 2. Hillside mire in Cazorla Park, southern Spain. *Coenagrion mercuriale* was common here.

- The permanent stream to the east of the mires – 60 m^3/hr.
- Through the mires – 15 m^3/hr.

The compromise solution, therefore, resulted in a change of flow from 75 m^3/hr to 15 m^3/hr, an 80% reduction. In addition, after 1996, the water entered the mire to the west of the original flow, which meant that a certain amount of the reduced water quantity was diverted away from the Mires. Since 1996 the mires have been starved of water and reliant upon rainfall to maintain their levels. In 2016, six visits were made to the mires and, on each visit, the author recorded the condition of the habitat (Table 2). At no time were conditions present that would support *C. mercuriale*. It is impossible to reach any other conclusion than that the mires at Povington are no longer suitable for this species.

However, on 8 July 2018, the author made another visit to Povington to see if there had been any changes to the water regime. On arrival it was clear that the Operator had installed a new pump which provided water specifically to the mires (Fig. 4, Plate 6). Previously, a separate pipeline had run from

Plate 3. *Coenagrion mercuriale in copula* photographed in Cazorla Park, southern Spain.

the claypit. This new pump was operating well and producing similar (probably more reliable) volumes to the mires to those measured in 2016 (i.e. 15m^3/hr); the overall impact on the mires was considerable. Bearing in mind that the visit was made during a period when rainfall had been very low and hot weather had prevailed for some weeks, both mires were noticeably wet and, particularly in Outflow mire, there was discernible flow.

Discussion

The mires at Povington must be seen as entirely man-made and, therefore, artificial habitat. Prior to 1985 there would have been no more than an irregular seasonal flow. With the expansion of the clay workings, habitat conditions were created for *Coenagrion mercuriale*, which was discovered in 1992. However, following the flow measurements it is clear that the conditions were only ever going to be temporary. The migration of the claypit to the east has meant that it is no longer practicable to discharge all of the outflow into the mires. The compromise solution (Prendergast, 1996) did not provide sufficient volumes of water to maintain the habitat, and, although the water flow to the mires had been increased, the improved conditions would be unlikely to attract a new population; however, they might support a small remnant population if it still exists. Futhermore, the problem in Purbeck, as it is in other regions, is that livestock numbers have greatly reduced in recent decades. This reduction

Plate 4. One of the heather bales used to control water flows - left high and dry in summer 2016. From Dieck (2009).

Table 1. Summary of the records of *Coenagrion mercuriale* from Povington, based on data from the Biological Records Centre, including records from E.D.V.Prendergast, A. Schofield, N. Armor Chelu, Rob Neal, C. Dieck and R. Aquilina. The RSPB produced regular counts up to 2006. Where "No records" are stated, it is not clear whether the site was visited. Surveys were undertaken in 2014, 2016, 2017 and 2018, which together produced only one record (of a male in 2016).

Year	1992	1993	1994	1996	1998	1999-2001	2002	2003	2004
Adults	200	405	242	284	73	No records	136	77	34
Year	2005	2006	2007-2008	2009	2010-2013	2014	2015	2016	2017-2918
Adults	75	80	No records	5	No records	0	0	1	0

means that the streams are no longer important as field boundaries and are neglected, and the reduction in grazing leads to the growth of scrub, rendering the habitat unsuitable, as has already occurred at Povington. Thus, in 1996, when the flows were entirely through the Povington mires, 500 cattle grazed the area. Many of these animals strayed into the mires, poaching the ground and controlling the vegetation. Today only a small number of cattle are seen and none come close to the mires. The consequent lack of grazing will slowly lead to the demise of the mires, irrespective of water flow. This does not mean

Plate 5. The author poised to carry out water flow measurements. Chris Chelmick on the stopwatch (not illustrated).

that the habitat is unsuitable for dragonflies generally; indeed *Ischnura pumilio* (Scarce Blue-tailed Damselfly) (Plate 7), which is another extremely local species restricted to Southern England, was recorded by both the author and Annabel King in 2016. This is very much a species of seasonal waters, which now prevail.

As mentioned above, there are six known sites for *C. mercuriale* on the Isle of Purbeck (Fig. 5). Of these six sites only one (Hartland Moor) has a thriving and stable population and this is about 6 km from Povington. The nearest extant site (Fig. 5) is Creech Heath, which is approximately 3.5 km from Povington. However, this site is also under threat and has had a greatly reduced population in recent years. In addition there are two further sites (Fig. 5) where only isolated specimens have been found. Bearing in mind the habitat neglect throughout the area, the chances of recolonization at Povington are very poor unless grazing can be increased considerably.

Table 2. Summary of the status of the Povington mires in 2016.

Date	Observer	Outflow Mire	Orchard Mire
		status	status
12-Jun-16	DGC	3	
18-Jun-16	DGC	4	
09-Jul-16	DGC	5	3
17-Jul-16	DGC	5	4
27-Jul-16	AK		
14-Aug-16	DGC	5	5
22-Oct-16	DGC	3	3

1	Water flow through the mires
2	Water present in the mire – but little flow
3	Isolated pools
4	Damp conditions
5	Dry

Only status 1 & status 2 would support a viable population of *Coenagrion mercuriale*. DCG, David Chelmick; AK, Annabel King.

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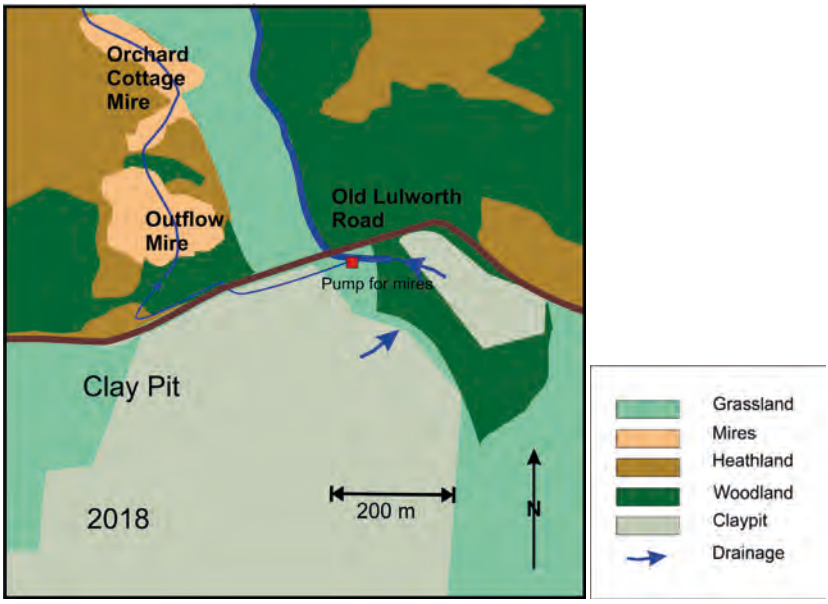

Figure 4. The Povington mires and their water supply in 2018.

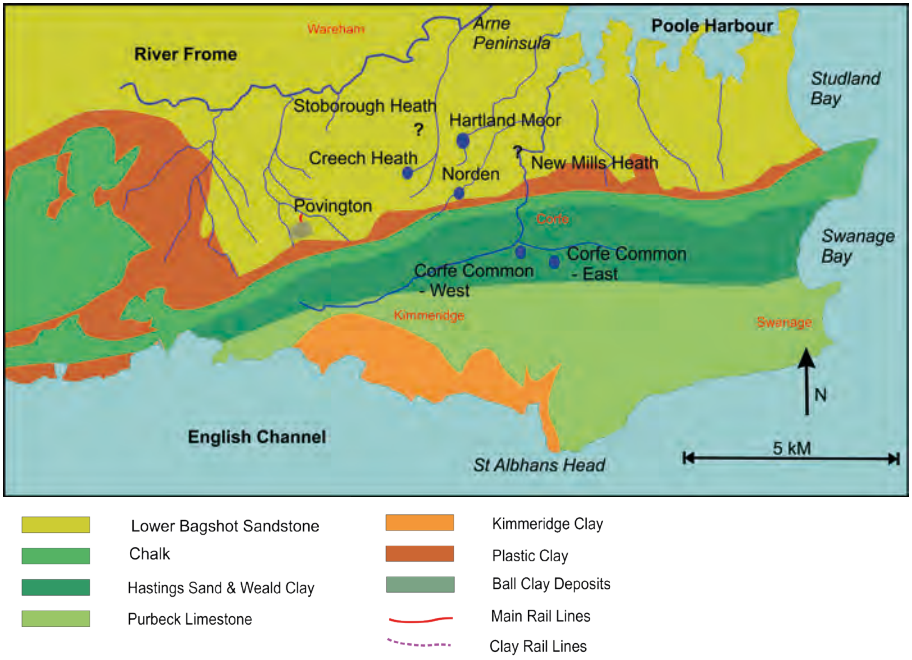

Figure 5. *Coenagrion mercuriale* in Purbeck. Red mark, the Povington site; blue dots, the other five breeding sites; ?, two sites where only isolated specimens have been recorded.

Plate 6. Water pump installed for the mires.

A B

Plate 7. *Ischnura pumilio*. A, male photographed at Povington in July 2016; B, *Ischnura pumilio aurantiaca* female photographed at Povington.

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Colour of the gonapophyses in *Cordulegaster boltonii* (Golden-ringed Dragonfly) can help determine the stage of metamorphosis in female final instar larvae

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Summary

The degree of darkening of the gonopophyses in female final instar (F-0) larvae of *Cordulegaster boltonii* (Donovan) (Golden-ringed Dragonfly) is compared with the four stages (here referred to as 1 - 4) of metamorphosis described by Ferreras-Romero & Corbet (1999) in this species. There is a reasonable degree of correlation, with larvae showing no darkening of the gonopophyses falling mainly in stages 1 and 2, whereas those with more than 25% of darkening fall almost exclusively into stages 3 and 4. The method described in the current study is a simple method for determining the stage of metamorphosis but it is suggested that, for maximum accuracy, both methods should be used.

Introduction

Before emergence, the larvae of odonates pass through successive stadia until reaching the final larval instar, named F-0. The number of stadia and the duration of each one varies with the species (Corbet, 2004). In temperate regions, diapause may occur in the winter, during which phase growth stops, and this is the case in *Cordulegaster boltonii* (Donovan) (Golden-ringed Dragonfly) (Ferreras-Romero & Corbet, 1999).

In the F-0 larvae, visible changes occur in the body surface that affect, the wing-sheaths, compound eyes and the prementum of the labium. Using these three structures, several authors have proposed different stages in the F-0 instar

to understand the progress of metamorphosis, both in zygopterans (Corbet & Prosser, 1986) and in anisopterans (Corbet, 1957; Norling, 1976; Ferreras-Romero & Corbet, 1999). For F-0 larvae of *C. boltonii* Ferreras-Romero & Corbet (1999) proposed four stages (here referred to as 1 - 4):

1) No external signs of metamorphosis
2) Metamorphosis evident
3) Metamorphosis advanced
4) Emergence imminent

The criteria they used included swelling of the wing sheaths, increasing anteromesial (black) extension of the compound eyes and darkening of the prementum, starting from its distal end (indicating a decrease in its internal tissue).

Knowledge about the stadia of larvae is important, because it allows us to determine the duration of instar F-0 and to anticipate when emergence will take place; also, whether the beginning of emergence differs between sites. These factors influence both the dynamics and the age structure of a population.

Methods

In this paper a character (colour of the gonapophyses) is proposed that can help to increase the degree of precision when female F-0 larvae are assigned to one of the four stages proposed by Ferreras-Romero & Corbet (1999). The gonapophyses can be pale coloured along their whole length or show various degrees of darkening (Plate 1). This dark colour results from the gradual loss of internal tissue from the tip proximally.

The usefulness of this character was determined in 130 female F-0 larvae collected in streams in the valley of the Eresma River, in the province of Segovia, Spain (40º 51'N 4º 1'W) between January 2017 and June 2018. In this area the emergence of *Cordulegaster boltonii* begins in mid-June and lasts approximately 60 days (Casanueva *et al*., 2017), and thus the collected larvae belonged to all stages of metamorphosis. The larvae were analyzed using an Olympus binocular microscope with an eyepiece micrometer. The length of the gonapophyses was measured according to the method of Verschuren (1989) and, when any darkening was present, the length occupied by the dark surface was also measured (Plate 1). From these measurements, the percentage of the length of the gonapophyses occupied by darkening was determined. Four degrees of the extent of this darkening were arbitrarily established:

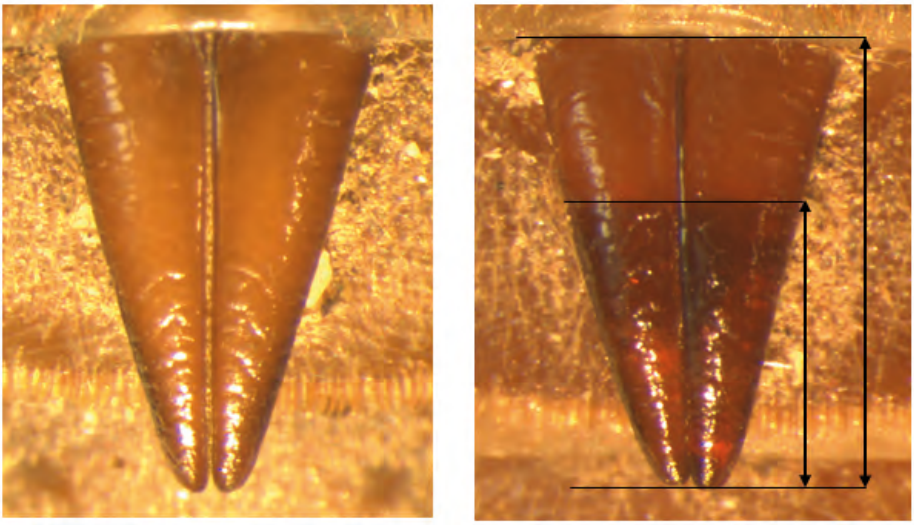

Plate. 1. Ventral view of the gonapophyses of a female *Cordulegaster boltonii* without (left) and with (right) a darkened region. The arrows indicate the measured lengths used to calculate the percentage length occupied by the dark region.

a) Absence of any dark colouration
b) A small dark bar (1-25%),
c) A dark bar of intermediate length (26-50%)
d) A wide dark bar (> 50%).

The larvae were also separated into one of the four stages established by Ferreras-Romero & Corbet (1999). The method described here can be used with a small pocket magnifying glass and has the advantage of being fast and simple. In addition, it is not necessary to kill the larvae to determine their stage.

Results

Of the 130 F-0 larvae analysed, seven were assigned to stage 1 of metamorphosis, 58 to stage 2, 52 to stage 3 and 13 to stage 4. The extent of the dark colour of the gonapophyses varied from 0% to 100% (Plate 1, Fig. 1).

Progressing from stage 1 to stage 4 there was a clear decrease in the number of F-0 larvae with no darkening of the gonapophyses from 100% in stage 1 to zero in stage 4 (Fig. 1). Those with 1-25% darkening comprised 26% of the larvae in stage 2, increased to 50% in stage 3 and then fell to 23% in stage 4. One individual assigned to stage 2 (i.e. 1.7%) fell into the range 26-50%

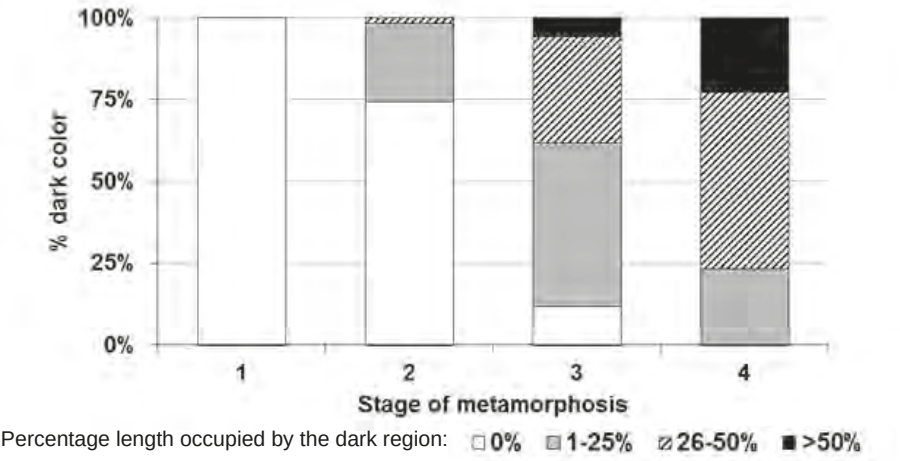

Figure 1. Percentage of female *Cordulegaster boltonii* F-0 larvae with varying degrees of darkening of the gonapophyses when the larvae were assigned to stages 1-4 of metamorphosis, as defined by Ferreras-Romerp & Corbet (1999). n=130.

darkening. By stage 3, 33% showed this range of darkening and this increased to 54% of larvae in stage 4. Darkening in excess of 50% was shown by 6% of the larvae in stage 3 and 23% of those in stage 4.

However, while it is clear that the extent of darkening progressively increased throughout the F-0 instar, there was not a precise correlation between the four degrees of darkening (as defined above) and the four stages defined by Ferreras-Romero & Corbet (1999). Thus stages 1 and 2 of Ferreras-Romero & Corbet (1999) correspond to those larvae without any darkening or with less than 25%, i.e. showing no or very little development of metamorphosis. Only one of the 65 larvae (i.e. 1.5%) assigned to these two stages had a dark colour that extended more than 25% of the length of the gonapophyses (Fig. 1). Those larvae assigned to stage 3 were the ones that presented the greatest uncertainty, due to a mixture of all four of the degrees of darkening (a-d) (Fig. 1). However, of those larvae assigned to stage 4, 76% had gonapophyses with more than 25% dark colouration.

Therefore, the absence of any darkening of the gonapophyses indicates a high likelihood that F-0 larvae belong to stage 1, whereas those with 25% or more darkening belong to either stage 3 or stage 4.

Discussion

There is a certain degree of overlap in the three characters used by Ferreras & Corbet (1999) to define the four stages of metamorphosis in F-0 larvae of *Cordulegaster boltonii*. For example, in stage 2, they found that only a few larvae showed some darkening of the prementum. Presumably these would be larvae approaching stage 3. In stage 3, some larvae had swollen wing sheaths but others did not, the former probably being larvae approaching stage 4. Similar degrees of overlap were found in the current study in terms of the degree of darkening of the gonapophyses. It is quite likely that those stage 2 larvae that showed some darkening of the gonapophyses were well-advanced within that stage and thus approaching stage 3. Similarly, those in stage 3 that showed >25% darkening may have been in the late phase of that stage.

In summary, the degree of darkening of the gonapophyses in *C. boltonii* gives a good indication of the stage of metamorphosis of final stage (F-0) larvae and correlates to a reasonable degree with the four stages described by Ferreras & Corbet (1999). Although it is a simple method for determining how close an F-0 larva is to emergence, the overlaps discussed above, and particularly the range of the extent of the darkening found in stage 3 larvae, indicate that both methods should be used for an accurate determination of the stage of metamorphosis that has been reached.

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