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Cover illustration: A male *Orthetrum coerulescens* at Sundon Quarry, Bedfordshire. Photograph by Steve Cham.

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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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  - Hammond, C.O. 1983. *The Dragonflies of Great Britain and Ireland* 2nd Edition (revised by R. Merritt), Harley Books, Colchester, 116pp.
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- Figures, plates and tables should be presented on separate, unnumbered pages.
- Legends for figures, plates and tables should be presented together in sequence on separate, unnumbered pages.
- 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	*Aeshna mixta*	Migrant Hawker
Calopteryx splendens	Banded Demoiselle	*Anaciaeshna isoceles*	Norfolk Hawker
Calopteryx virgo	Beautiful Demoiselle	*Anax ephippiger*	Vagrant Emperor
Ceriagrion tenellum	Small Red Damselfly	*Anax imperator*	Emperor Dragonfly
Chalcolestes viridis	Willow Emerald Damselfly	*Anax junius*	Green Darner
Coenagrion armatum	Norfolk Damselfly	*Anax parthenope*	Lesser Emperor
Coenagrion hastulatum	Northern Damselfly	*Brachytron pratense*	Hairy Dragonfly
Coenagrion lunulatum	Irish Damselfly	*Cordulegaster boltonii*	Golden-ringed Dragonfly
Coenagrion mercuriale	Southern Damselfly	*Cordulia aenea*	Downy Emerald
Coenagrion puella	Azure Damselfly	*Crocothemis erythraea*	Scarlet Darter
Coenagrion pulchellum	Variable Damselfly	*Gomphus flavipes*	Yellow-legged Club-tail
Coenagrion scitulum	Dainty Damselfly	*Gomphus vulgatissimus*	Common Club-tail
Enallagma cyathigerum	Common Blue Damselfly	*Leucorrhinia dubia*	White-faced Darter
Erythromma najas	Red-eyed Damselfly	*Leucorrhinia pectoralis*	Large White-faced Darter
Erythromma viridulum	Small Red-eyed Damselfly	*Libellula depressa*	Broad-bodied Chaser
Ischnura elegans	Blue-tailed Damselfly	*Libellula fulva*	Scarce Chaser
Ischnura pumilio	Scarce Blue-tailed Damselfly	*Libellula quadrimaculata*	Four-spotted Chaser
Lestes barbarus	Southern Emerald Damselfly	*Orthetrum cancellatum*	Black-tailed Skimmer
Lestes dryas	Scarce Emerald Damselfly	*Orthetrum coerulescens*	Keeled Skimmer
Lestes sponsa	Emerald Damselfly	*Oxygastra curtisii*	Orange-spotted Emerald
Platycnemis pennipes	White-legged Damselfly	*Pantala flavescens*	Wandering Glider
Pyrrhosoma nymphula	Large Red Damselfly	*Somatochlora arctica*	Northern Emerald
Sympecma fusca	Winter Damselfly	*Somatochlora metallica*	Brilliant Emerald
		Sympetrum danae	Black Darter
ANISOPTERA	DRAGONFLIES	*Sympetrum flaveolum*	Yellow-winged Darter
Aeshna affinis	Southern Migrant Hawker	*Sympetrum fonscolombii*	Red-veined Darter
Aeshna caerulea	Azure Hawker	*Sympetrum pedemontanum*	Banded Darter
Aeshna cyanea	Southern Hawker	*Sympetrum sanguineum*	Ruddy Darter
Aeshna grandis	Brown Hawker	*Sympetrum striolatum* *	Common. Darter *
Aeshna juncea	Common Hawker	*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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Thoracic spur variations in *Chalcolestes viridis* (Vander Linden) (Willow Emerald Damselfly) and their use in identifying territorial males.

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Abstract

Chalcolestes viridis is still a new and uncommon species in Northamptonshire, with low populations densities at all sites where it is found. Territorial males are very mobile, flying between several perching sites, which makes assessing colony size difficult. The maximum number of adults recorded at any one site in Northamptonshire is 25, but the real number is unclear due to the mobility of this species. In order to better measure colony size, variations in the thoracic spur markings were analysed to find a method of separating individuals as they move around territories. Measurements were taken of the light yellow/green area on the thorax and its associated spur. Calculations of the Root Mean Square variance of its shape and size were found to provide the best methodology for identifying individuals.

Introduction

Chalcolestes viridis has been steadily spreading north and west in England since the first potential colonist was recorded in Suffolk in 2007 (Cham *et al*., 2014). By 2018 it had reached Lincolnshire in the north and Buckinghamshire in the west (Parr, 2019). Northamptonshire lies between Lincolnshire and Buckinghamshire and *C. viridis* remains a rare species in the county, and its colonies are still small. During the 2019 season, records were obtained from a number of new sites but with adults seen in single figures only (Tyrrell, 2019a). The pond at Finedon Pocket Park (Tyrrell, 2019b) remains the primary site, where adults and oviposition scars were first found in 2016 following a major expansion in eastern England at that time (Parr, 2017). Since it was first found at Finedon, adult numbers remained below ten until 2019 when, on 19 September, the highest recorded number of adults reached a peak of 25, declining thereafter (Tyrrell, 2019a).

The territorial behaviour of adult males, moving from branch to branch in willows overhanging water, and the high mobility of tandem, mating and ovipositing pairs makes assessing population sizes difficult, as there is a high degree of uncertainty whether the same insect has been counted more than once. The most common method for identifying individual odonates in a colony is the Mark-Release-Recapture (MRR) method, where individuals are identified by marking a wing with a unique number or coloured spot. They are then released, and future sightings note these numbers. With modern digital photography, the recapture stage can often be replaced by a photograph. MRR is 100% reliable but is a delicate process, only really suitable for trained recorders and is not suitable when adults are mating or for newly emerged individuals.

On each side of the thorax there is a yellow/green area, from which projects a 'spur' (Parr, 2016). This paper explores variations in this area as a means of identifying individual males as an aide to assessing colony size.

Material & Methods

Adult male *Chalcolestes viridis* are approachable when perched, so hi-resolution digital photographs were taken with a Canon 5DS R at 50 megapixels with a Canon 100mm f2.8 L series macro lens, at f8. This combination gives good sharp images that reveal variations in the size and shape of the yellow/green area on the lower side of the thorax and allows large enlargements to measure these variations. All images were taken of the left side of the adult on the same willow tree at Finedon Pocket Park, Northamptonshire, over several visits. Images were imported into Adobe Illustrator CC and vector paths drawn around the yellow/green area (Plate 1). Vector paths allow scaling without loss of quality. All resulting vector paths were scaled to a length of 220mm using the Transform Scale tool in Adobe Illustrator, set to Uniform. This was to account for any variation in magnification at the image capture stage.

The vector images were aligned so that the longest line joining the furthest extremes of the yellow/green area was at 0 degrees. A number of measurements were then made from the images (Fig. 1) to assess if any differences could be detected between individuals that might lead to identifying the same individual in different images:

- Angle of the spur.
- Ratio 1. The ratio of the length from the posterior end of the mark to the base of the spur (a) to the overall length (x)
- Ratio 2. The ratio of the width from the base of the spur to the ventral surface of the mark (b) to the overall length (x)

Plate 1. Adult male *Chalcolestes viridis* with the Vector path around the yellow/green area and its spur shown by the red open circles.

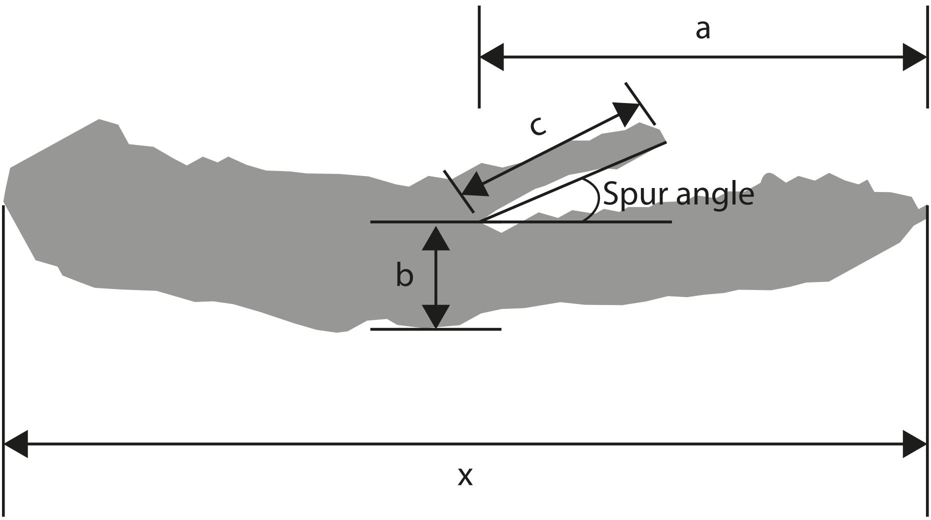


Figure 1. Redrawn image of the yellow/green thoracic marking and spur, showing the measurements made to assess similarities and differences between individuals.

- Ratio 3. The ratio of the length of the spur (c) to the overall length (x)
- Total area.

Eight separate images were studied, taken over several visits, and defined by their image file number (Fig 2). The images are shown in the sequence they were taken, such that, for example, image 6 was the 6th image taken on that day and image 4 the 4th on a different day.

Measurements were taken from each image as noted in the previous section (Table 1). All measurements were made using the tools in Adobe Illustrator, except area, which was from a downloaded script (Buchanan, 2015) run in Adobe Illustrator.

On reviewing the images, it was noted that the insect in images 14 and 18 exhibited characteristic eye damage (Plates 2A, B) showing that they are the same individual and thus providing a good control to examine the data for consistencies.

Pairs of images were aligned so that their centre lines (x in Fig 1) were coincident and a series of 30 equally spaced points were selected to cover the complete circumference (Fig. 3) for measurement of the Root Mean Square (RMS) variance which is based around mean standard errors of variances in size and shape (Wirth, 2004). At each point the difference between the two images was measured in centimetres. The measurement points were kept consistent for all pairs assessed.

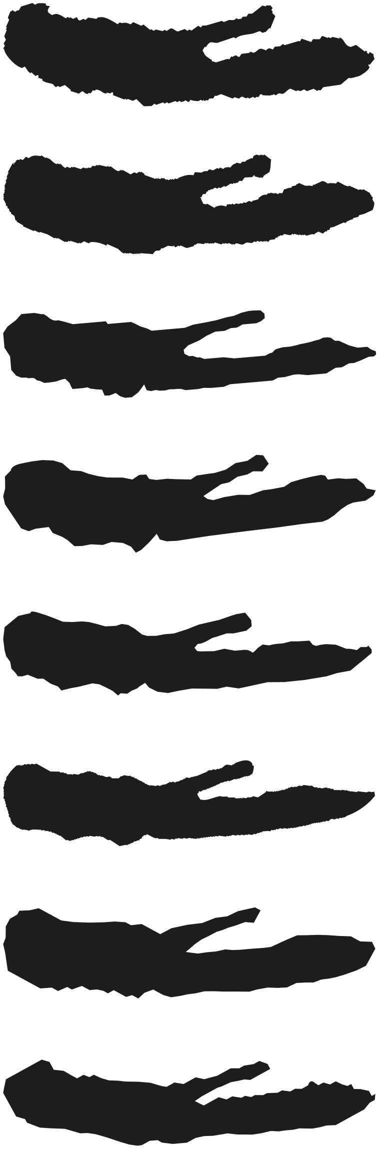
RMS differences were calculated using the following equation in Microsoft Excel 365.

$$RMS = \sqrt{\frac{[d1^2 + d2^2 + d3^2 + ...dn^2]}{n}}$$

Where:
dn = distance in mm between the chosen points (Fig 3).
n = total number of points sampled

Results

The ratios, spur angle and total area (Table 1) varied considerably and made it difficult to identify whether or not images were from the same individual. Images 14 and 18 are known to come from the same insect (Plate 2A, B) and the ratios from these two images are identical but there were small differences in the spur angle and the total area, which could have resulted from small, indiscernible,



6

4

2

36

14

18

11

22

Figure 2. Redrawn thoracic spurs in the order in which they were recorded. Numbering is according to the camera file name. File numbers are sequential over one day and are reset for subsequent days.

A

B

Plate 2. The same adult male of *Chalcolestes viridis*, providing images 14 (A) and 18 (B), showing identifiable eye damage (arrowed).

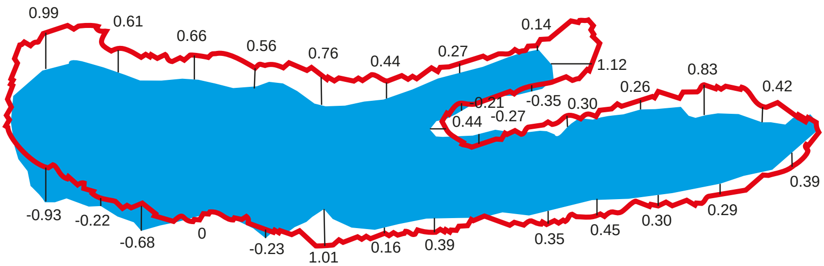


Figure 3. Measurements of the difference between individuals leading to the calculation of Root Mean Square variance, as demonstrated by comparing image 11 (red) with image 22 (blue).

Table 1. Measurement results for the eight thoracic spur images studied. Ratio 1, the ratio of the distance from the posterior end of the mark to the base of the spur (a) to the overall length (x); Ratio 2, the ratio of the width at the base of the spur (b) to the overall length (x); Ratio 3, the ratio of the length of the spur (c) to the overall length (x). See Figure 1.

Image	Ratio 1	Ratio 2	Ratio 3	Spur Angle, degrees	Area, relative to image 6
6	0.46	0.14	0.21	17	1.000
4	0.47	0.12	0.21	20	1.001
2	0.53	0.11	0.23	22	0.793
36	0.46	0.12	0.18	26	0.887
14	0.47	0.11	0.16	23	0.812
18	0.47	0.11	0.16	26	0.821
11	0.51	0.12	0.12	27	0.927
22	0.48	0.10	0.10	24	0.811

differences in the angle at which they were photographed. From these data it looks as though images 4 and 6 may also be from one individual (Plate 3A, B) as the ratios and total area are similar, the latter indeed being more similar than that between images 14 and 18. However, the spur angle differed by three degrees. Image 22 also had a very similar area to image 14 but differed from it notably in Ratio 3.

The Root Mean Square (RMS) variance was thus used to see if the discrimination between individuals could be improved. Values are presented in the form of a matrix showing all comparisons (Table 2). This technique scores high RMS variances when insects are different and, ideally, zero when they are the same. In practice, images of the same individual are likely to show a low value because of slight differences in camera angle, redrawing and orientation. It should be

A

B

Plate 3: Two images (4 (A) and 6 (B)) of adult *Chalcolestes viridis* identified as being the same individual using the Root Mean Square variance technique.

Table 2. Root Mean Square variances in size and shape between all pairs of images. The values highlighted in green are for those pairs of images that are from the same individuals, i.e 4 & 6 and 14 & 18

Image	6	4	2	36	14	18	11	22
6								
4	0.06							
2	0.43	0.40						
36	0.30	0.31	0.36					
14	0.53	0.37	0.30	0.28				
18	0.33	0.36	0.24	0.29	0.08			
11	0.32	0.26	0.28	0.33	0.30	0.29		
22	0.40	0.39	0.34	0.28	0.28	0.31	0.35	

noted that the values depend on the scaling of the images so analysis should focus on the relative differences in the values (Table 2).

The results show that the two images (14 and 18) of the known individual gave a very low RMS variance (<0.1) confirming what is known from the photographs (Plate 2A, B) that these were the same individual. Furthermore, this analysis further confirmed that images 4 and 6 are also highly likely to be from a single individual as their comparison also gave an RMS variance of <0.1 (Plate 3A, B). All the other comparisons yield an RMS variance of at least 0.24 and hence are highly likely to be different individuals. Thus it is clear that images 14 and 22 are not from the same individual as their RMS variance comparison was 0.28.

Conclusions

Chalcolestes viridis exhibits variations in thoracic spur markings in both size and shape that can be used to identify individuals from a small population, allowing an assessment of population size to be made. The method that gave the most reliable results was the Root Mean Square (RMS) variance; this was demonstrated by two images from the same male, taken on separate occasions, giving a low RMS variance value. Ideally this technique should be investigated further by combining it with a Mark-Release-Recapture (MRR) study.

Since the RMS variance technique can be used to determine if different images are or are not from the same individual, it is not limited to assessing colony size but can be used for any study where identifying individuals is important. For example, it can be used to assess movement of individuals between trees when examining territorial behaviour and mating success.

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On the discovery of a ‘new’ population of *Orthetrum coerulescens* (Fabricius) (Keeled Skimmer) in a chalk quarry and factors affecting its continued survival

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Abstract

Orthetrum coerulescens was first discovered at Sundon Quarry, Bedfordshire in 2017. This is a chalk quarry and hence is atypical of other sites where *O. coerulescens* is found. In 2018 and 2019, higher numbers of adults were recorded, along with larvae and exuviae, confirming the presence of a breeding population. The Sundon population is one of the more inland populations in Britain and is some distance from the next known breeding site. It is considered to be vulnerable due to the small-scale nature of the habitat. Shallow seepages and runnels in base-rich sites are a scarce type of habitat and may explain the under reporting of any association of *O. coerulecens* with such sites. The continued survival of this colony of *O. coerulecens* will depend on a number of factors including whether the site can be managed to maintain the open seepage habitat and water supply that the species requires.

Introduction

In Britain *Orthetrum coerulescens* (Keeled Skimmer) has been considered to be restricted by its habitat requirements to lowland heath and moorlands (Merritt *et al*., 1996). Various authors have referred to it as being one of a number of acidophilic species associated with runnels, streams and pools, where bog mosses and associated plants such as *Potamogeton polygonifolius* (Bog Pondweed), *Narthecium ossifragum* (Bog Asphodel), *Hypericum elodes* (Marsh St Johns Wort) and *Eriophorum angustifolium* (Common Cotton Grass) are found (Corbet *et al*., 1960; Welstead & Welstead, 1984). The breeding success at less acidic sites was poorly known (Smallshire & Swash, 2004); not until relatively recently has it been reported and proven to breed at other habitat types, including calcareous fens such as Cothill in Oxfordshire (Cham *et al*., 2014; Smallshire & Swash 2018). In Ireland it is predominantly found at flushes

Plate 1. *Orthetrum coerulescens* (Keeled Skimmer) male at Sundon Quarry on 4 August 2018.

and pools in heaths and bogs yet also occurs at base-rich flushes, the bottom of which are covered by putty-coloured flocculent mud (Nelson & Thompson, 2004).

During the summer of 2017, several adult male *O. coerulescens* were observed in an area of shallow runnels at Sundon Quarry in Bedfordshire. These sightings represented the first ever records for this site as well as for the county (Plate 1). It was initially considered that these were wandering or dispersing individuals and therefore a one-off occurrence. After its discovery by Lol Carmen, small numbers of adults were observed on several visits by the author throughout the summer of 2017. However, males and females were subsequently recorded in higher numbers during 2018 and again in 2019 with confirmed proof of breeding. This is the subject of this paper.

Sundon quarry is a chalk quarry and hence is a new and very different type of habitat for this species in Britain. It is also a considerable distance from the nearest known colony of *O. coerulescens* at bog pool flushes at Burnham Beeches (Fig. 1). Furthermore, these sightings were in the same area of spring-

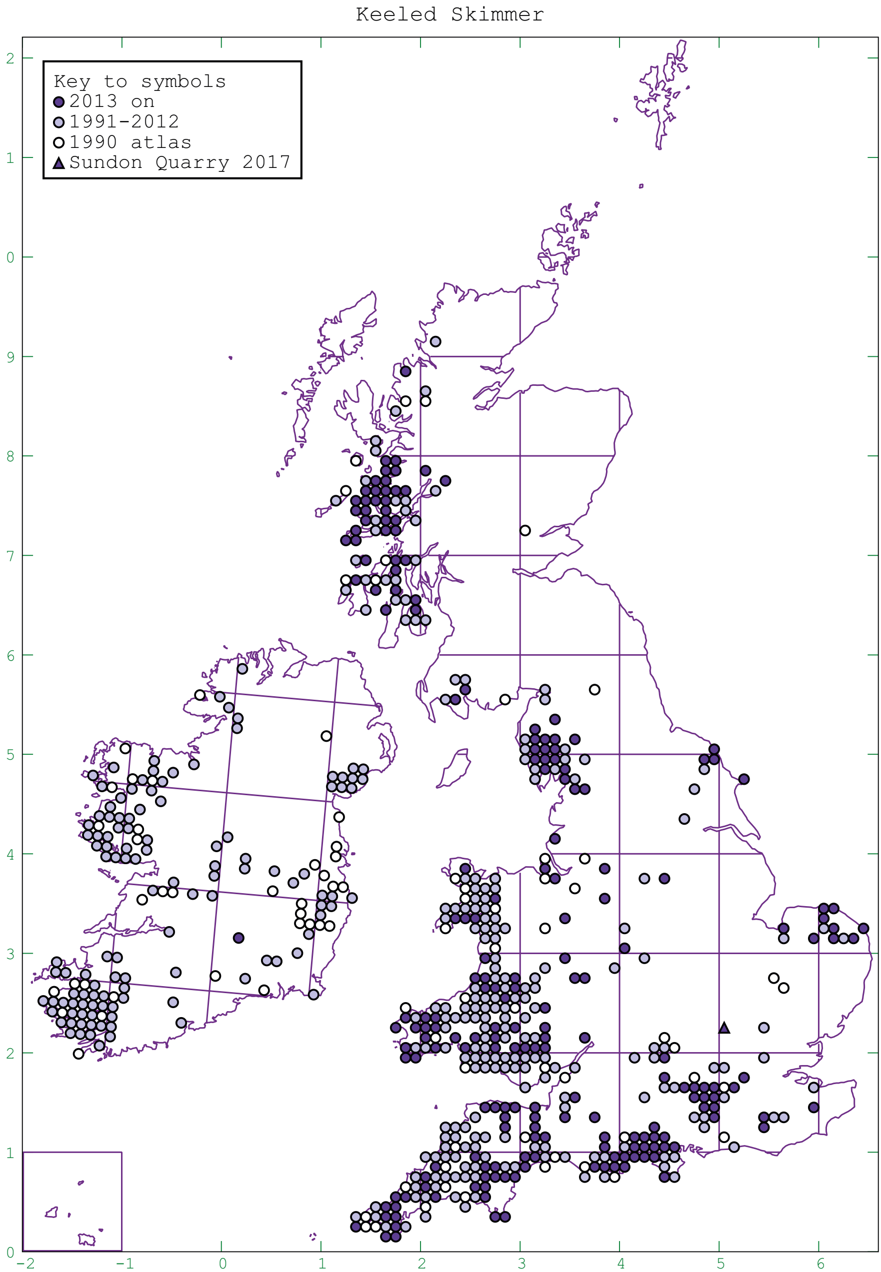

Figure 1. Distribution of *Orthetrum coerulescens* (Keeled Skimmer), showing the location of Sundon quarry. Symbols based on 1990 atlas (Merrit *et al.*, 1996), 1991-2012 (Cham *et al.*, 2014, 2013 on (BDS database).

line seepages where a population of *Ischnura pumilio* (Scarce Blue-tailed Damselfly) formerly bred and it was with the expectation of rediscovering that species that led Lol Carmen to discover *O. coerulescens*.

Methods

Due to the significance of the initial sightings in 2017, follow up visits were made in 2018 to assess the population. Higher numbers of both males and females were observed, with pairs in cop and ovipositing observed at seepage pools and runnels. These observations were very suggestive that *Orthetrum coerulescens* was breeding at Sundon Quarry. As it is regarded to have a two-year life cycle its abundance in 2018 suggested that it may have already been present but overlooked in 2016.

In order to establish breeding status, further visits were made during the winter of 2018/19 to search for developing larvae. A kitchen hand sieve was used to sample the muddy chalk substrate in the shallow seepages and runnels. These shallow seepage pools are characterised by early growth of *Chara* sp. (a charophyte green alga) and *Eleocharis palustris* (Common Spike-rush).

Further visits to search for exuviae were made throughout June 2019 in anticipation of emergence and the adult flight period, and to assess the breeding status at Sundon. During each visit exuviae were removed to avoid double counting on subsequent visits.

Results

During a winter visit on 23 February 2019, larvae of *Orthetrum coerulescens* were abundant in small pools no more than 1m x 2m with a water depth of less than 5cm. By passing the sieve through the water and surface layers of the bottom chalk sludge, larvae quickly revealed themselves by movement. They were abundant in those pools characterised by early stages of plant growth, conditions that are not dissimilar to the areas favoured by *Ischnura pumilio* when it was present. At this early time of the year the larvae had already entered their final instar. Final instar larvae were prevalent. However, there were also some much smaller larvae, presumably belonging to the following year's cohort.

On 30 June 2019, exuviae of *O. coerulecens* were found at two small pools in the upper seepage area at Sundon. Emergence was recorded approximately 2-10 cm above the ground on plant stems close to the pool margins (Plates 2, 3). This was the first confirmation of successful breeding in the seepage pools.

Plate 2. Exuviae (arrowed) of *Orthetrum coerulescens* in a seepage pool at Sundon Quarry.

Plate 3. Exuviae (arrowed) of *Orthetrum coerulescens* in a seepage pool at Sundon Quarry.

On the same day fully mature adults were observed, including a pair in cop. Thus emergence had been missed in the preceding weeks.

On 13 July 2019, newly emerged adults were observed flying up from the seepage pools. This led to the discovery of 34 exuviae of *O. coerulescens* spread over three small pools. On 3 August 2019, a number of adult males were holding territory across the seepage area. By this time *Sympetrum striolatum* (Common Darter) was also present and emerging. Exuviae of *S. striolatum*, which are similar in size to those of *O. coerulescens*, were also recorded in the same areas. Fortunately, exuviae of the two species are relatively easy to distinguish based on head shape and relative leg length (Cham, 2012). Larvae and exuviae of *O. coerulecens* have smaller and less prominent eyes, giving the impression of smaller head size, while the relatively shorter legs of this species give the larvae a more squat appearance.

By 17 August 2019, numbers had declined, with only three males present at the seepages and pools. Approximately 12-15 *S. striolatum* were also present on the pools with some emergents. Based on the above data, the estimated emergence period of *O. coerulescens* is from mid-June until the end of July.

Discussion

Sundon Quarry is a former cement works which operated between 1899 and1976. Much of the quarry is designated as an SSSI of 26.17 hectares in size and has a range of habitats including lakes, chalk grassland, species-rich scrub and developing woodland. It is currently privately owned and crossed by footpaths that provide access to parts of the site. The middle part of the quarry complex includes wetland habitat comprising small fishing lakes. These lakes are 1-2m deep. An adjacent smaller pool 0.3m deep is becoming increasingly invaded by emergent plants. The regular removal of aquatic plants and use of weedkillers by the fishing club creates very turbid water, which limits their attractiveness to odonates. Despite this, a small breeding population of *Platycnemis pennipes* (White-legged Damselfly) has persisted at the site for some years.

Away from the lakes, the southern end of the quarry complex and the area where *Orthetrum coerulescens* breeds comprises a deep chalk quarry where springs seep out at the base of cliffs and run through the quarry, forming small shallow seepage pools and runnels (Plates 4, 5). These soak into the base of the quarry, forming a small area of damp scrub.

Sundon quarry and the nearby Houghton Regis quarry became notable following the discovery of breeding colonies of *Ischnura pumilio* in 1987

Plate 4. Sundon quarry runnels viewed from the top of an adjacent cliff.

Plate 5. Sundon quarry seepage pools viewed from the top of an adjacent cliff.

(Comont, 1988; Cham, 2004). The seepages at Sundon were maintained by the frequent disturbance from ‘unauthorised’ off-road vehicles which were the prime agent in maintaining the open nature of the runnels and seepages that attracted *I. pumilio* to breed at the site. The site is also ‘attractive’ to local car thieves and is scattered with burnt out vehicles. As a privately owned site the exclusion of these activities at the time resulted in plant succession and the open runnels quickly becoming overgrown with vegetation such as *Phragmites* sp. (reed). The colony of *I. pumilio* declined and finally disappeared. Attempts, in 2010, to restore the habitat under the guidance of Natural England were undertaken using a mechanised digger (Plate 6). A series of small and shallow pools were formed along the base of the cliffs, allowing the spring line to flow into the pools and runnels. The site was monitored in subsequent years but *I. pumilio* did not reappear. Succession continues to provide a threat to these areas especially from *Phragmites* sp. The unauthorised activities of off-road vehicles still continues at the site, affecting some areas and creating a dilemma for the conservation and management work at the site. As well as creating wheel ruts and runnels, this activity is also beneficial in maintaining open dry areas which demonstrably benefit *Cupido minimus* (Small Blue Butterfly) where its food plant *Anthyllis vulneraria* (Kidney Vetch) is in abundance.

The future of the seepage pools and runnels will depend on the water supply filtering into the spring lines. The summer of 2018 experienced long dry spells with a shortage of water. Water levels were lower than average with some of the pools drying out, especially in the base of the quarry. Areas where males were observed during 2018 became dry over the winter period. Vehicle activity maintains bare open ground, which benefits a range of flora and fauna by preventing plant seral succession. Furthermore, it creates wheel ruts that fill with water, which attracts rare invertebrates including *O. coerulescens*. However, being uncontrolled it can also cause the water flow to become diverted, resulting in some runnels becoming dry. Some of these are pools where *O. coerulescens* had been observed ovipositing.

Other species of Odonata that could potentially compete or predate developing larvae occur in the seepage pools where *O. coerulescens* is breeding. *Sympetrum striolatum* emerges slightly later, yet overlapping with the emergence of *O. coerulescens. Libellula depressa* (Broad-bodied Chaser) and *Libellula quadrimaculata* (Four-spotted Chaser) occasionally breed in the same pools. *Ischnura elegans* (Blue-tailed Damselfly) and *Pyrrhosoma nymphula* (Large Red Damselfly) also breed. Shallow seepages and runnels are generally free of fish and larger vertebrate predators. Newts (*Lissotriton vulgaris* (Smooth Newt) and *Triturus cristatus* (Great crested Newt)) are occasionally present. It is possible that these conditions are relatively safe for *O. coerulescens* females when searching for breeding sites.

Plate 6. Creation of shallow seepage pools at Sundon quarry using a mechanical digger to strip away the top soil first and then form a herringbone pattern of pools.

The origins of the *O. coerulecens* colony at Sundon are unknown and likely resulted from dispersal from other colonies over some distance. The nearest known breeding population to Sundon is 56km south at Burnham Beeches in Buckinghamshire. The next is 80km west at Cothill Fen/Dry Sandford near Oxford. Occasional wandering adults have also been recorded in Essex and Hertfordshire, to the east of Sundon, but to date no known breeding colonies have been found in those counties.

The occurrence of *O. coerulecens* at Sundon chalk quarry initially came as a surprise as superficially the site would be regarded as atypical habitat for this species. Many publications on British dragonflies refer to a strong association of *O. coerulecens* with acid conditions and there has been a tendency to describe dragonfly habitats in terms of their chemical properties and plant species composition. This can be misleading in understanding the habitat requirements of Odonata. At the time of the discovery of *I. pumilio* at chalk quarry sites in Bedfordshire the perceived wisdom was that this species also required acid bogs and runnels. "*A chalk quarry is the last place one would find Ischnura pumilio*" (Cham, 2004). Discovered in 1987 it persisted at Sundon until it was last recorded in 2005.

Plate 7. Warren Heath, Hampshire - seepages and boggy pools on acid heath where *Orthetrum coerulescens* breeds.

Corbet (1999) referred to '*habitat architecture*' to describe the proximate cues that dragonflies use to select suitable habitat for breeding. The microhabitat conditions in the shallow seepages and runnels at Sundon Quarry are not that dissimilar in physical structure to other favoured habitats on acid heathland (Plate 7). Brooks (1994) described the impact of acidity on the distribution of species thought to be associated with acid water conditions and he drew attention to the physical structure of the habitat being far more important in affecting species distribution than pH. Plant architecture can be very similar yet comprising very different plant species. The base-rich flushes in Ireland where *O. coerulescens* breeds are similar structurally to heath and bog pools but differ in their vegetation (Nelson & Thompson 2004). The new population reported here is in a calcareous seepage, a habitat that is extremely scarce. Indeed, calcareous seepages and runnels rarely get a mention in guides to habitat (Lake *et al*., 2015)

Acknowledgements

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Some observations on the life history and behaviour of *Aeshna affinis* Vander Linden (Southern Migrant Hawker)

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Abstract

Aeshna affinis (Southern Migrant Hawker) has become a regular breeding species in the UK in recent years. Much of its life cycle is little known. This paper details the author's field observations, in both Spain and the UK, of some aspects of its habitat, life cycle and adult behaviour. It is hoped that this will encourage more field observations so that a full understanding of its life cycle can be used to help conserve this apparently expanding species.

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Introduction

Aeshna affinis (Southern Migrant Hawker) is a locally common, mainly Western Palearctic, dragonfly (Kalkman & Dyatlova 2015). Since a large invasion of adults into southern England in 2010 (Chelmick 2011a), it has become a regular breeding species in the Thames Estuary (Chelmick 2011b) and appears to be expanding to other areas. The author has been studying this species in both Spain and the UK for a number of years and the purpose of this paper is to provide details of the following:

- Habitat and altitude
- Larval life cycle
- Oviposition behaviour

Iberian records included here are taken from the author's Dragonfly Database which contains:

- 6842 records
- 795 sites
- From 24 of the 47 Spanish Provincias primarily from the east and south

- From 5 of the 18 Portuguese Distritos in the central area and the southern coast.

The majority of the records were provided by the author, but other contributions are included along with historical published information. The database is updated annually and shared with Provincial recorders and, particularly, Florent Prunier, organiser of ROLA (Red de Odonatos de Libelullas Andalucia).

Observations

Altitude and Habitat

In Central Spain, the author has recorded *Aeshna affinis* from seven localities, in six of which it almost certainly breeds, as males have been found on territory and pairs seen ovipositing. Habitats are all at altitude as follows:

- Maximum 1,353 m asl
- Minimum 632 m asl
- Average 932 m asl

This is clearly atypical of central Europe where it is “…rarely observed above 700 m asl” (Kalkman & Dyatlova 2015), although Grand & Boudot (2006) stated that isolated individuals have been seen at 1,100m asl in the Massif Central. In Central Spain the habitat is fairly uniform and best described by the Spanish expression “Lagunas Estacionales”. These are shallow seasonal lakes which, in the majority of cases, dry out during the hot Iberian summer. They are often situated in the centre of arable cultivation and are almost invisible from the ground. Modern technology has revolutionised the identification of previously unknown sites and the Laguna de Tordesilos in Guadalajara Province (40^{0}39.15’ N. 1^{0}33.191’ W), approximately 160 km due east of Madrid, is a perfect example. From the road, a small copse of trees and a children’s play area are all that are visible (Plate 1), although the presence of *Circus aeruginosus* (Marsh Harrier) in summer indicates something more interesting.

However, it is only by viewing the site on Google Earth that the potential of this isolated habitat is revealed (Plate 2). The Laguna is a shallow depression of approximately 15 hectares in area and a perimeter of approximately 1.5 km. This oasis, clearly visible from the air, sits in the centre of a vast rolling tract of arable cultivation midway between the small towns of Tordesilos and Rodenas, which are approximately 14km apart.

The vegetation of the Laguna is dominated by *Scirpus sp.* (Bullrush) and *Typha*

Plate 1. Laguna de Tordesilos viewed from the adjacent track looking south.

spp (Reedmace) with *Juncus spp* (rushes) and *Schoenoplectus spp* (club rushes) forming an almost impenetrable barrier to the centre and providing protection for the marsh harriers which regularly breed here. Water levels are extremely variable. In most years, during the summer and autumn, there is permanent water in only the very centre, which represents no more than about 10% of the area. The perimeter is normally dry at this time of year. However, in August 2013, following a wet spring, there was standing water in more than 50% of the Laguna. *Aeshna affinis* was present in large numbers mainly around the stands of reedmace. Of further interest was the presence of large numbers of *Sympetrum flaveolum* (Yellow-winged Darter) in copula and ovipositing in the dry grassy areas of the perimeter.

Another example of this habitat is the Laguna Higuera (38°47.006' N. 1°24.544' W) in Albacete Province, approximately 100 km south west of Valencia. (Plate 3). As a result of the aspect of the land, this site is easily visible from the road and is similarly situated in a large area of arable cultivation. The site is much smaller than Laguna de Tordesilos (approximately 1 hectare) and comprises an exposed area of marsh with no protective hedges or trees.

Plate 2. Laguna de Tordesilos. Courtesy of Google Earth. The numbers in the yellow boxes are road numbers.

Plate 3. Laguna Higuera from the adjacent track in June 2019.

This Laguna is dominated by Juncaceae and *Schoenoplectus* spp) with *Scirpus lacustris* and *Phragmites australis* (Common Reed) providing some protection but only along the northern perimeter. The vegetation here is much shorter (Plate 4) than at Laguna de Tordecilos and thus offers a very exposed habitat. The author had visited this Laguna in November 2018 when the entire marsh was bone dry. On 14 June 2019, he visited it again with Roger Wicks . There

Plate 4. Laguna Higuera at close quarters to show the height of the vegetation.

was no standing water but some parts of the marsh were damp with oozing mud. At least five emerging *A. affinis* were seen. Despite not finding exuviae, there was no doubt that this was the breeding habitat, as the insects were too teneral to have flown any distance (Plate 5). *Lestes dryas* (Scarce Emerald Damselfly) was also found emerging here, which is the first record for Albacete Province. This species is often found with *A. affinis* in the UK.

Species association

As mentioned above, the author has observed *Aeshna affinis* at a total of seven localities in Spain and recorded it on eleven occasions. To date, 22 species have been recorded cohabiting with *A affinis* (Table 1), all of which are either multi or univoltine species (Corbet *et al*., 2006) able to cope with the seasonal nature of the habitat. Two species, *Lestes barbarus* (Southern Emerald Damselfly) and *L. virens* (Small Spreadwing), were seen at all sites where *A. affinis* was observed; six other species occurred at more than 50% of the *A. affinis* sites (Table 1). Of note is the appearance on the list of *Lestes macrostigma* (Dark Spreadwing), which is being recorded from a number of sites in central Spain at the time of writing (Chelmick & Diaz, in press).

Larval Life Cycle

Grand & Boudot (2006) stated that the larval life of *Aeshna affinis* is little known but that most authorities consider a life cycle of 2-3 years from egg to adult with a winter diapause. In temporary waters, it is suggested that larvae aestivate amongst the dried, dead vegetation. The alternative view is that the larvae hatch in March and April following a winter diapause and then emerge in

Plate 5. A recently emerged *Aeshna affinis* at Laguna Higuera.

early summer (June-July) of the same year. Corbet *et al*. (2006) stated that one author has suggested univoltine (1 year) whilst three others have stated that the life cycle is greater than 2 years and that the habitat is permanent.

The author's observations from central Spain strongly suggest that larval life very much reflects that of the species with which it is invariably associated i.e. *Lestes barbarus* and *L. virens*. *Lestes* species in the western palearctic are all univoltine, hatching in early spring following a winter diapause, and subsequently emerging in early summer (Jodicke, 1997). None of the species with which it is recorded (Table 1) has more than a one year life cycle and there appears to be no evidence to show why *A. affinis* does not have a similar larval behaviour. In the uplands of central Spain, summer and autumn can be extremely hot, with temperatures in excess of 40^{o}C. During such times these habitats are bone dry with dead vegetation, providing little respite. It is impossible to see how the larvae could survive this hostile environment.

Observations of larvae at West Canvey in Essex show that *A. affinis* is found most commonly with *Lestes dryas* in a veritable 'soup' of tiny invertebrates (Plate 6). There is clearly no shortage of food and rapid larval development is thus achievable. Schiel & Buchwald (2015) described *A. affinis* as a vernal pond species, which would support the view that it is univoltine.

Table 1. Species recorded co-habiting with *Aeshna affinis*, showing the number of sites and records. Those species occurring at more than 50% of the *A. affinis* sites are highlighted in blue.

	sites	records
Aeshna affinis	7	11
Lestes barbarus	7	16
Lestes virens	7	12
Sympetrum fonscolombii	6	14
Ischnura graellsi	5	15
Sympetrum meridionale	5	6
Ischnura pumilio	5	9
Sympecma fusca	5	8
Enallagma cyathigerum	5	6
Sympetrum sanguineum	3	10
Anax imperator	3	7
Ischnura elegans	3	8
Aeshna mixta	3	4
Coenagrion scitulum	3	5
Lestes dryas	3	3
Crocothemis erythraea	2	8
Lestes sponsa	2	7
Orthetrum cancellatum	2	5
Sympetrum striolatum	2	5
Sympetrum flaveolum	1	5
Libellula quadrimaculata	1	2
Lestes macrostigma	1	2

Oviposition Behaviour

Aeshna affinis can often be seen with *A. mixta* (Migrant Hawker), which is a similar sized dragonfly. Superficially they look similar (for differences see Chelmick, 2011a). Although often found in the same localities, the oviposition behaviour is quite different. *Aeshna mixta* females invariably lay singly, often with the male nearby. They lay in the stems of vegetation, usually above the surface of water, but can also lay below the surface (Plate 7A). *Aeshna affinis* adopts a quite different approach. Adult males hold territory in specific areas of the marsh. They avoid standing water but do seek out the most low-lying areas.

Plate 6. A larva of *Aeshna affinis* feeding on a *Lestes dryas* larva.

In the UK these are usually areas poached by cattle or ditch crossing points used by cattle. In the arable areas of Spain, such large domesticated mammals are unusual and the depressions occur as a result of wild mammals such as deer, pigs or wild boar (Plate 8). These are areas most likely to flood early in the Spring and thus provide the best hope for hatching. Oviposition is carried out by the pair in tandem and is usually directly into damp ground, most notably in the foot holes of cattle or other large mammals (Plate 7B).

Choice of oviposition site by dragonflies is almost invariably left to the females. However, males of *A. affinis* can be seen apparently checking the ground conditions prior to mating. At West Canvey in Essex (TQ 779853), where *A. affinis* is now a regular breeder, the most favoured areas are where cattle have crossed the ditches. In 2019 males were observed flying into particular footholes and pushing their abdomens around parts of the ground, presumably testing its suitability for oviposition (Plate 9). This is not an isolated observation as Richard Seidenbusch (pers comm.) confirmed that he also observed this behaviour some years ago in Austria.

The advantages of oviposition into the footholes is obvious (Plate 10). Plate

A

B

Plate 7. (A) a female *Aeshna mixta* ovipositing. Photograph taken in Southern Italy by Fons Peels (Dragonflypix.com), (B) a female *Aeshna affinis* oviposting in a foothole at West Canvey, UK.

Plate 8. A Wild Boar wallow from a Laguna in Central Spain (inset - skull of the Wild Boar) – an ideal habitat for *Aeshna affinis* to oviposit.

10A shows the dry footholes made by the cattle in August. Plate 10B shows the early flooding, which fills only the footholes, allowing for early hatching and the best possibility of larval development.

Communal roosting

Hawker dragonflies (Aeshnidae) can often be observed late in the evening feeding away from water. On 29 June 2018, a male *Aeshna affinis* was

A

B

Plate 9. (A and B) a male *Aeshna affinis* inspecting a foothole at West Canvey, UK.

A B

Plate 10. Cattle footholes at West Canvey UK. (A) dry footholes in August ready for oviposition, (B) flooded footholes in December.

observed at 20:30 local Spanish time (one hour ahead of British Summer Time) patrolling a stream near the town of Munera in central Spain. It was clearly not holding territory but taking advantage of the stream and its associated insects; feeding prior to roosting. This was the second locality where the author had witnessed this late feeding by *A. affinis*. Thus, on 14 July 2011, Anthony Winchester and the author were at Los Charcones Nature Reserve (39^{0}30.985' N. 3^{0}3.296' W) near the town of Miguel Esteban in Toledo Province, one of the known breeding sites for this species. On arrival (around 20:30 local Spanish time) a large number (50 +) of small hawker dragonflies were noticed flying in a frenzy along the track and over the adjacent vegetation. They would not settle and one had to be netted (subsequently released) to confirm identification. The collected insect was a female *A. affinis* (Plate 11A).

The insects were obviously feeding prior to roosting and, as the light faded,

A

B

Plate 11. Los Charcones Nature Reserve. (A) a female *Aeshna affinis* caught while feeding prior to roosting, (B) a roosting male *Aeshna affinis*.

Plate 12. Los Charcones Nature Reserve. The track immediately north of the marsh where *Aeshna affinis* were observed feeding prior to roosting, mainly in the Tamarisk bush shown here.

so they gradually reduced in number. A large *Tamaris gallica* (Tamarisk) bush appeared to be the area of choice and both sexes of *A. affinis* were observed roosting communally here (Plates 11B & 12). On a second visit to this locality, on 2 August 2013, at a similar hour the same behaviour was observed.

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First exuviae of *Anax ephippiger* (Burmeister) (Vagrant Emperor) found in the Maltese Islands

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Summary

Despite several tandems of *Anax ephippiger* (Vagrant Emperor) having been regularly observed ovipositing in the autumn in the Maltese Islands in recent years, no evidence of a resulting generation had come to light. In November 2019, two exuviae belonging to this species were found, confirming the successful breeding of this species.

Introduction

The main breeding range of *Anax ephippiger* is in North Africa, the Middle East and South-west Asia but it often breeds in parts of southern Europe.. The larvae grow rapidly and breeding is usually in shallow waters, both permanent and temporary (Lambret & Boudot, 2011). Lambret & Boudot (2011) noted that it is an obligate migrant which commences its migration early in the post-teneral stage. There are also records from central Europe and the British Isles, and it is the only dragonfly recorded in Iceland (Askew, 1988; Dijkstra & Lewington, 2006). Generally, but not exclusively, migratory individuals are usually seen in the Autumn (Askew, 1988). Ovipositing tandems have been seen as far north as England, but breeding has not so far been confirmed (Parr, 2019). However, numerous exuviae were recorded in The Netherlands in 2019, providing proof of breeding there (Manger, 2020).

The status of the Vagrant Emperor has recently been reviewed by Gauci (2014, 2018). In 2017-2019, there was a notable increase in autumn numbers, including several ovipositing tandems (Gauci, 2019). However, despite this, no evidence of a resulting generation has been found. Sciberras (2011) reported a teneral male on *Foeniculum vulgare* (Fennel) at il-Qammieh (a stretch of rocky coast in the north/north-west region of Malta) on 23 August 2010, claiming it to be the first record of successful breeding of the species in the Maltese Islands. Sciberras (2011) noted that the fennel plant was situated “just above an almost waterless rock pool, where some water retained between the crevices of the bottom mud slabs. An accurate search for the exuviae was carried out, but none were recovered.”

Observations

In 2019 the author saw the first *Anax ephippiger* of the autumn on 17 September and noted the first ovipositing tandem on 24 September. Subsequently, several tandems were regularly observed ovipositing until 20 November, followed by a late sighting, with the female having extremely tattered wings, on 6 December. Most observations were made at the five reservoirs found in the Chadwick Lakes valley system, stretching over about 3 km from below Mtarfa to just outside Mosta. Below each dam forming these reservoirs a fairly large rocky pool forms, one of which is more open than the others and in which one or two tandems of *A. ephippiger* were regularly observed ovipositing when it was full after the first autumn rains. When the rock pool was initially full at the end of September, six species were observed ovipositing in it. Apart from *A. ephippiger,* these were *Anax imperator* (Emperor Dragonfly), *Anax parthenope* (Lesser Emperor), *Orthetrum trinacria* (Long Skimmer), *Sympetrum fonscolombii* (Red-veined Darter) and *Crocothemis erythraea* (Scarlet Darter).

This rock pool (Plate 1) covers an area of about 25 m^2 when full and has the shape of a funnel. It loses water fairly quickly and, when there is a long period between rainy spells, it tends to dry up. Following a prolonged dry spell in October, this rock pool was in the process of drying up completely and, on 25th October the author decided to remove as many of the larvae from the pool as possible and transfer them to three small ponds in his garden and an aquarium on his roof (Plate 2). In total about 30 *Anax* spp. and 10 *Sympetrum fonscolombii* larvae were transferred.

On 24 November, following a windy night, a smallish *Anax* exuvia was found in a corner of the roof 3 m. away from the outdoor aquarium. Its size, shape of the eyes and the prementum all pointed to it being *A. ephippiger*. On 29 November an identical exuvia was found by the aquarium. Both exuviae (Plate 3).belonged to males and were 44 mm long, compared to the 45-56 mm for *Anax imperator* and *A. parthenope* (Cham, 2007). Indeed, size is on average 10 mm shorter than these other two species of *Anax*. Also the prementum is broader and relatively shorter than in *Anax imperator* and *A. parthenope*, as is illustrated in Manger (2020). Locally, all *Anax* species emerge during the night and fly off before daybreak.

On 17 December a largish dragonfly was found behind one of the planters near the aquarium. It turned out to be a female *A. ephippiger* with a damaged left

Plate 1. The rock pool from where about 30 larvae of *Anax* spp. were transferred to three small garden pools and an outside aquarium.

forewing (Plate 4), rendering it unable to fly. It was in a very poor condition, presumably because it had emerged a few days earlier when the Maltese Islands had been hit by very strong winds and heavy rain. The exuvia was not found, no doubt having been blown off by the gale force winds.

Discussion

Dumont and Desmet (1990) gave the duration of the larval stage of *Anax ephippiger* as around 100 days. During the past few years *A. ephippiger* has been found ovipositing regularly in the Maltese Islands in late autumn, mostly October and November (Fig. 1). Based on this 100-day duration of the larval period, the resulting emergence of a new generation would be expected in mid-winter to early spring. However, no evidence of a spring generation has ever been found (Gauci, 2019). Since this strongly migratory species occurs mostly in the dry regions of Africa and Asia (Dijkstra & Lewington 2006), this could possibly be due to the low water temperatures during the winter months, rendering larval survival unlikely. About sixty larvae which had hatched from

Plate 2. The aquarium into which eight *Anax* spp. larvae were introduced in late October 2019.

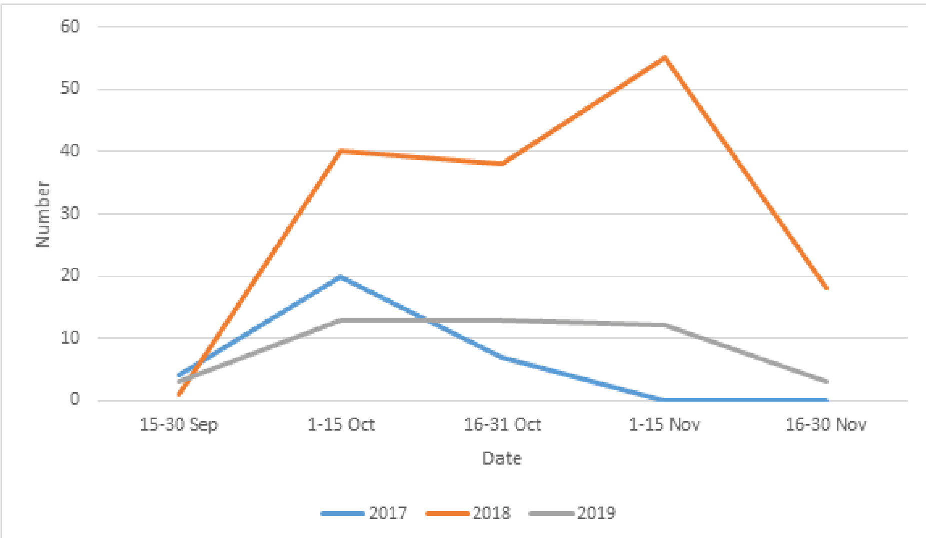

Figure 1. The number of ovipositing tandems of *Anax ephippiger* in the autumns of 2017-2019.

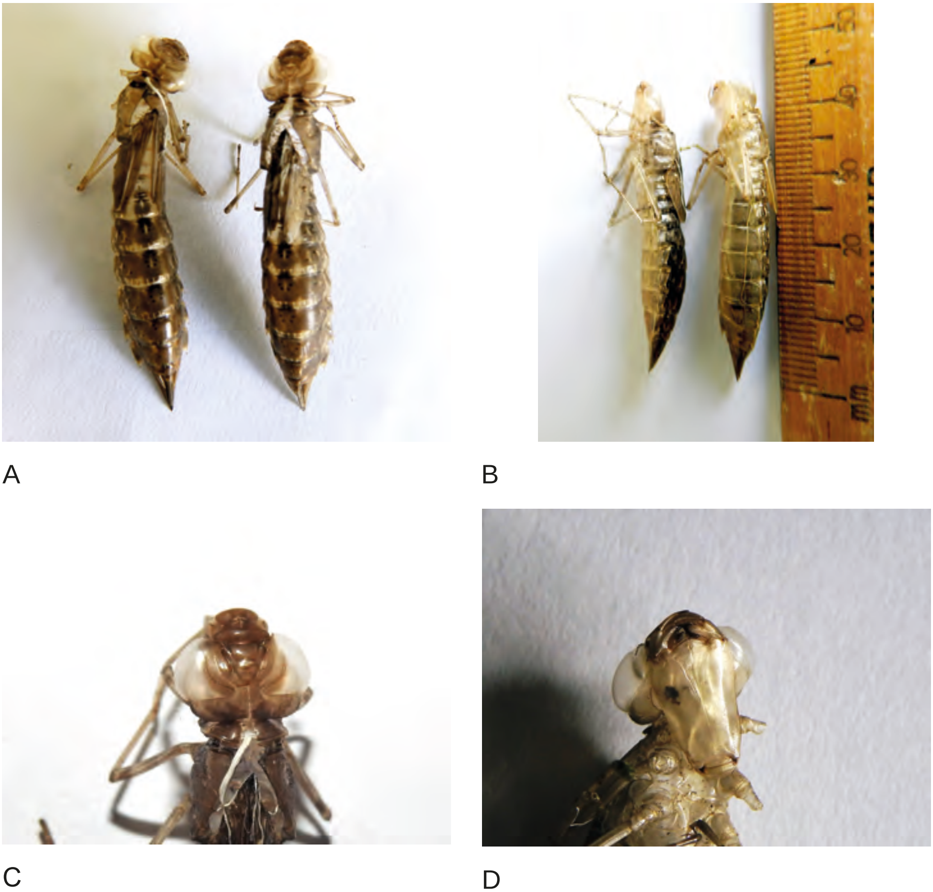

Plate 3. The exuviae of *Anax ephippiger* that were found near the roof aquarium. (A) dorsal view, (B) lateral view, showing the length of the exuviae, (C) the head of one of the exuviae to show the shape of the eyes, (D) the prementum of one of the exuviae to show its shape.

a piece of expanded polystyrene on which an *A. ephippiger* tandem had been seen in prolonged oviposition, and which the author had transferred to an outside aquarium and two small ponds in November 2018, all gradually disappeared, presumably dying after hatching in the first half of December (Gauci, 2019). Following a huge invasion in central Europe in late spring, 2019 saw the first successful breeding of this species in central and northern Europe (e.g. Denis Matthey, pers.com.; van der Heijden, 2019; Manger, 2020). Moreover, Matthey (pers. com.) found that, from a leaf with *A. ephippiger* eggs which he transferred to his pond in the Prague area of the Czech Republic on 8 June 2019, several larvae hatched and about 40 adults emerged between 1

Plate 4. The adult female *Anax ephippiger* with a damaged wing that had presumably emerged from the aquarium.

August and 5 September, giving a larval period of just 54 days. In Malta, most ovipositing tandems are observed between early October and mid-November (Fig. 3). Following Matthey's findings (Matthey, 2019), eggs laid locally in late September – early October should see the resulting larvae attain emergence by late November. At this time of year water temperature is still relatively high and it is quite plausible that at least some *A. ephippiger* have been emerging unnoticed. As in the other *Anax* species, tenerals move away from water and are seldom encountered. It is also possible that these would migrate south soon after emergence. During this period strong winds and heavy rain showers are not uncommon and exuviae would not last long. Moreover, the author has never conducted any specific searches for exuviae at this time of the year since the 100 days larval stage duration given by Dumont and Desmet (1990) would have meant that any surviving larvae would not emerge before about mid-January.

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