Dragons in the Dales
Full report:
A species recovery project looking at peatbog dragonflies on restored peatlands in Yorkshire and studying the habitat requirements for white-faced darter reintroductions

YORKSHIRE PEAT PARTNERSHIP

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Introduction

Background

Leucorrhinia dubia, or the white-faced darter, is a peat-bog dragonfly which particularly thrives on lowland raised bogs (Boudot & Kalkman, 2015). This is a small red (male) or yellow (female) dragonfly with a creamy-white face, which requires bog pools covered with *Sphagnum* bog mosses to breed (Henrikson, 1993). The first documented record for *L. dubia* in Britain was made in Yorkshire, in Thorne Moor in 1837; unfortunately, it has become extinct in this county since the middle of the last century (Merritt et al, 1996).

In England and Wales today, the white-faced darter is restricted to a handful of sites and is now classed as Endangered on the British Red List (Daguet et al., 2008). The State of Dragonflies 2021 report revealed that the three species which have declined the most are also peatbog dragonflies: the black darter (*Sympetrum danae*), common hawker (*Aeshna juncea*), and emerald damselfly (*Lestes sponsa*) (Taylor et al, 2021). The decline of all these species is likely because of habitat loss and degradation of our precious peatlands, which have faced many threats such as industrial peat extraction for horticulture, draining for agriculture and development, and burning for game shooting.

But all is not lost for these peaty dragonflies. In recent years, several reintroduction programmes have managed to translocate the white-faced darter to old and new habitats in Staffordshire (Beynon, 2001), Cumbria (Clarke, 2014) and Cheshire (Meredith, 2017), and there are a number of other reintroduction programmes in progress elsewhere such as in Lancashire.

Furthermore, organisations in the UK, such as Yorkshire Peat Partnership (YPP), are now working to restore our peatlands and bring them back to boggy health. This involves blocking drainage channels, reprofiling eroding peat hags, revegetating bare peat, and planting bog plants such as *Sphagnum* mosses. As of 2024, YPP has brought 45,592 hectares of peatland into restoration management across the Yorkshire Dales and North York Moors National Parks, Nidderdale National Landscape, and beyond in the Great North Bog (YPP Annual Report, 2024).

Whilst the aim of this peat restoration work is the re-wetting of these vast and important peatlands, the outcomes of this work are far more wide-reaching, boosting biodiversity because healthy peat bogs are home to rare and special wildlife, such as the white-faced darter.

Aims and Objectives

In 2023, YPP was granted funding from Natural England’s Species Recovery Programme. This project, ‘Dragons in the Dales’, was focused on the red-listed white-faced darter dragonfly and the priority peatbog dragonflies: the black darter, common hawker, and emerald damselfly.

In this study, we surveyed four peatlands which are under restoration delivered by Yorkshire Peat Partnership and present the dragonfly survey results. One of the sites was surveyed systematically for the first time across a whole season and we present the important role that volunteers played in this data collection. Finally, we discuss the design of a school trip to a local bog and the engagement monitoring results.

With the increased interest in white-faced darter reintroductions across the country, there is a need to collate and review the data on this species. Therefore, we set out to produce a literature review of the distribution and past reintroduction programmes of *L. dubia*.

Equipped with this database of habitat requirements, the next objective was to apply this to a real-world site by developing a Habitat Suitability Index based upon aerial imagery and known field survey data. Our chosen target site was Swarth Moor, a SSSI lowland raised bog with associated lagg fen habitat in the Yorkshire Dales; this site has now had two rounds of peat restoration works to fix the hydrology and peatland vegetation.

The final objective was to investigate the current and future suitability for white-faced darter across the Yorkshire area and beyond to Great Britain. This will enable us to predict how climate change and changing weather patterns may affect the future of the white-faced darter in the coming decades.

PART 1: LITERATURE REVIEW

1.1. ABSTRACT

The UK population of *Leucorrhinia dubia*, or white-faced darter dragonfly, only subsists in a handful of fragmented strongholds. As a key bog species, the presence of *L. dubia* is a good indicator of the health of peatlands. However, since the 19th Century humans have exploited these places and climatic pressure have had significant impacts on their ecological functioning. Therefore, today *L. dubia* is Red Listed by the British Dragonfly Society and is considered extinct in some parts of the UK. Rewetting and revegetating can make these habitats resilient to future changes. This type of enhancement work can also restore some important environmental aspect essential to the reintroduction of *L. dubia*.

In Part 1 of this report, we review data and evidence collected on natural populations and reintroduction program sites to provide quantifiable estimates on the best habitat parameters for the reintroduction of *L. dubia* in North Yorkshire, UK. Our results show that near-natural or restored raised bogs with a high density of *Sphagnum*-covered bog pools and a nearby tree cover are ideal places for *L. dubia* to thrive. To help a *L. dubia* colony to establish itself and thrive in a new area, its habitat needs to bigger, better and more joined up, as per the Lawton Principles.

As biodiversity gain is becoming an important outcome of habitat restoration for project funders, this type of evidence gathering work might need to be conducted more often in the future. Lessons can be learnt from reintroduction programs. Data should be collected in systematic way and shared widely to refine reintroduction protocols.

1.2. INTRODUCTION

Leucorrhinia dubia, or white-faced darter, is a peat-bog dragonfly which particularly thrives on lowland raised bogs. This habitat, home of many invertebrates and wading birds, are characterised by a rich flora, including peat moss (*Sphagnum* moss), sedges and rushes. This habitat is defined by the presence of a surrounding tree cover, an abundance of shrubs and acidic bog pools. The pools are used as hunting grounds for the dragonflies and the females use floating, feathery bog-moss (*Sphagnum cuspidatum*) to lay their eggs.

Since the 19th century, the extent of active lowland raised bog in the UK has declined from ~95,000 ha to only ~6000 ha, of which only 500 ha are in England (Natural England, 2020). Of what is left, a large proportion of English lowland raised bog are degraded due to drainage, over-grazing and atmospheric pollution. The degradation of peatlands directly impacts fundamental ecological services such as carbon storage (Lindsay, 2010), the preservation of historical records (Gillingham, 2016) and water filtration (Bottrell et al., 2004). Changes in ground water quantity and quality puts them at risk from drying out, increasing the risk of erosion, wildfires, and biodiversity decline (Berry & Butt, 2002; Bottrell et al., 2004; Gillingham, 2016; Lindsay, 2010). Climate change and an increasingly fragmented habitat (Taylor et al., 2021) are a direct threat to many invertebrate and bird species. *L. dubia* is now listed as a vulnerable species on the 2024 European Red List with a current stable trend through Europe (Boudot & Kalkman, 2015). In Britain, it is Red Listed by the British Dragonfly Society (Daguet et al., 2008) and it is now considered extinct from Yorkshire and the Humber. However, the dragonfly had been absent from Cheshire for ten years before it was reintroduced in 2013, and several reintroduction projects are working to secure the future of the white-faced darter.

Over the years, charities and partnerships have worked to restore the ecological services provided by peatlands to make them more resilient to future climatic changes. In Yorkshire, the Yorkshire Peat Partnership (led by Yorkshire Wildlife Trust) has brought nearly 43,000 hectares of peatlands into restoration management[1]. To date, the primary aim of restoration has been to restore peatland hydrology through grip and gully blocking and stop erosion through groundwork and revegetation. However, during restoration, numerous species are found to benefit from the newly formed bog pools (**Figure 1.1**) (Beadle et al., 2015; Strobl et al., 2020), including dragonflies and damselflies, which have been observed using the still water as breeding sites. Habitat reconstruction could therefore also be considered a high priority outcome of peatland restoration and peatland practitioners may consider adapting their working practices to match the needs of a specific priority species (or set of species), such as the white-faced darter dragonfly.

To that end, this contribution provides an exhaustive assessment of the environmental conditions necessary for the reintroduction of *L. dubia* in North Yorkshire. Information gathered will help implement appropriate restoration practices, such as Sphagnum planting, to make peatland bogs ready for the release of dragonflies. This type of habitat enhancement work might also benefit other declining dragonfly species such as black darter (*Sympetrum danae*) and common hawker (*Aeshna juncea*) (Beadle et al., 2015). This literature review was done as part of the Dragons in the Dales project[2], a dragonfly reintroduction project led by the Yorkshire Peat Partnership (yppartnership.org.uk).

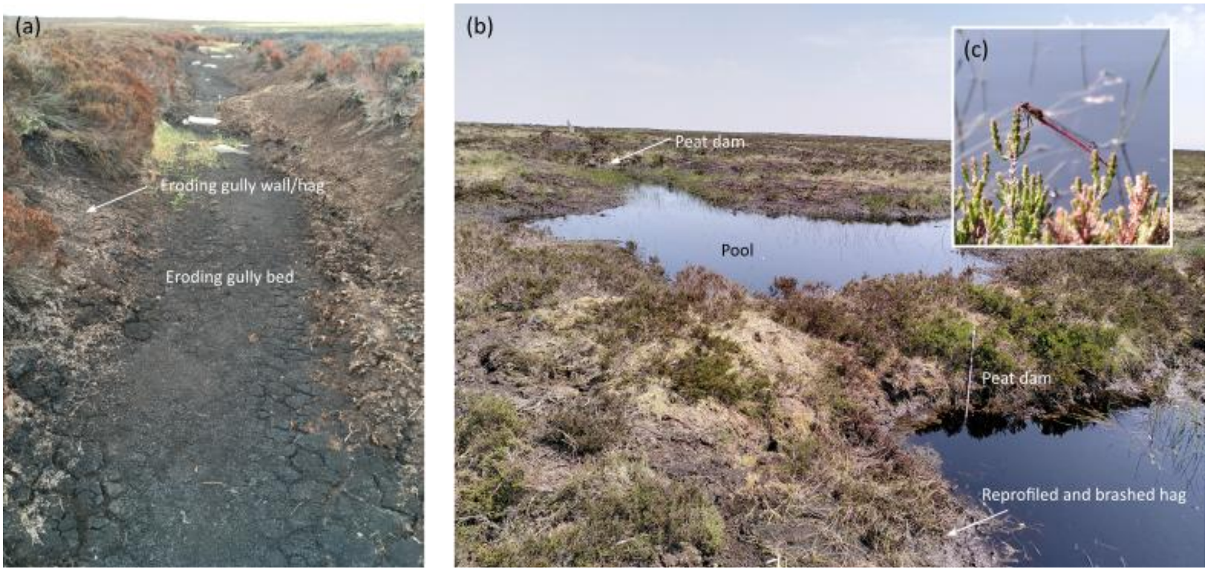

Figure 1.1 – Effect of restoration on peatland habitats. Formation of bog pools in the North York Moors. (a) prior restoration (2020). (b) after restoration (2023). Following the installation of peat dams in summer 2023, the population of dragonflies, damselflies (c – Large Red Damselfly - Pyrrhosoma nymphula*) and wading birds were observed using the newly formed pools as watering holes and breeding sites (photographs: YPP).*

[1] Yorkshire Peat Partnership 15 year report (https://www.yppartnership.org.uk)
[2] https://www.yppartnership.org.uk/dragons-dales

1.3. DISTRUBUTION AND OCCURRENCE OF *L. DUBIA*

1.3.1. Global distribution

L. dubia is one of the most widespread dragonflies in Russia and northern Europe. It is referred to as *L. dubia dubia* subspecies west of the Ural Mountains and *L. dubia orientalis* subspecies in the eastern boreal region. It is notably absent in the warmest and driest part of Asia (Boudot & Kalkman, 2015).

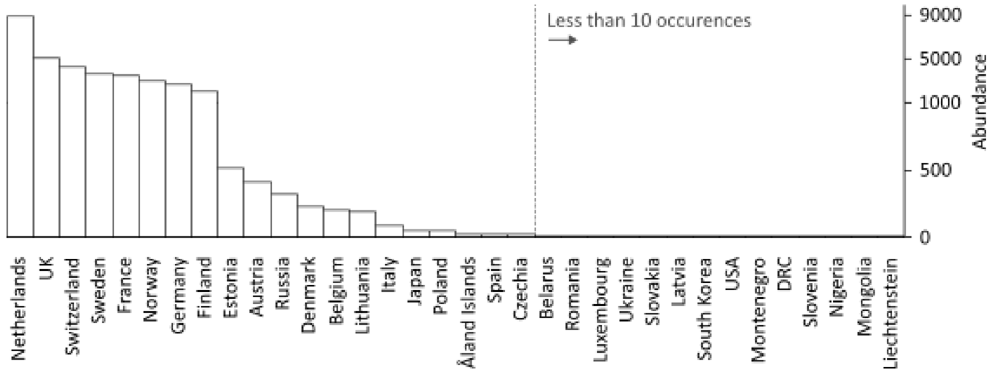

Figure 1.2 - Total abundance of L. dubia sighting per country for the period 1799-2023 (GBIF, 2024)

The species is common in central and northern Europe where more than 99% of occurrences have been recorded between 1799 and 2023 (GBIF, 2024). However, the distribution of white-faced darter is not homogeneous throughout Europe. Most observations come from Scandinavian countries, France, Germany, Switzerland, the UK, and the Netherlands (**Figure 1.2**). It is worth noting that most eastern European countries are not included in the database due to the limitations inherent to large data aggregators (GBIF, 2024). *L. dubia* is believed to be much more common than presently known in a large part of Belarus and northern and central European Russia. It has been found as far as the Kamchatka Peninsula and Tuva region in Russia (Boudot & Kalkman, 2015; Kosterin & Zaika, 2010). This species is rare in Ukraine but was found at the beginning of the 20th century in the Kyiv region and at altitudes > 1500 m in the Carpathian Mountains. There have been some more recent records in the northeast part of Ukraine (Khrokalo & Nazarov, 2008). Records at the Romanian/Ukrainian border define the southern limit of its distribution in the Carpathians and in East Europe (Kovács & Murányi, 2008). Although the species occurred on both its German and Lithuanian borders, only rare instances have been recorded in Poland (Bernard et al., 2009).

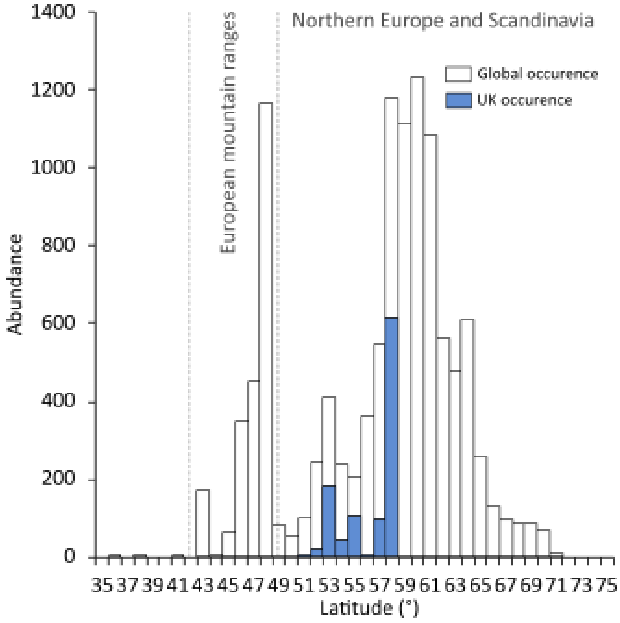

Figure 1.3 – Total abundance of Leucorrhinia dubia sighting per latitude for the period 1799-2023 (GBIF, 2024)

In the rest of Europe, the distribution of the white-faced darter shows a strong affinity for high latitudes and mountainous regions (Dolný et al., 2018; Macagno et al., 2012) (Figure 1.3). In the Alps, the species is confined to altitudes above 1000 m. In the Spanish Pyrenees, multiple adults and larvae of *L. dubia* have been found in high-altitude (> 2000 m) mountain lake of Estanys (Michiels & Verheyen, 1990). The distribution in the UK indicates that white-faced darters mostly occur in Scotland (1.3). Although at lower altitudes than its southern European counterparts, the Scottish climate might provide similar conditions those found in European mountain ranges.

1.3.2. UK distribution

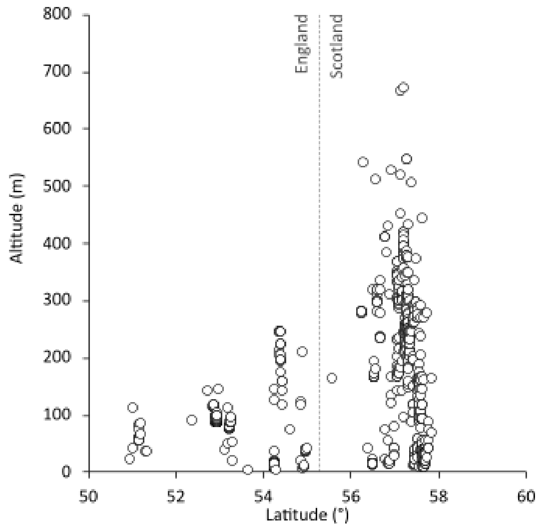

Figure 1.4 – Occurrence of L. dubia in the UK according to site's elevation and latitude.

Data on the occurrence of *L. dubia* in the UK were compiled using the NBN Atlas database ranging from 1800 to 2022 (NBN Atlas, 2023). There is a strong positive correlation between

L. dubia presence, latitude and altitude, with most of the observed dragonflies being reported in Scottish glens (**Figure 1.4**). On average, an altitude between 31 m and 261 m and latitudes between 54.01°N and 57.94°N seem to provide adequate habitat conditions for *L. dubia* in the British Isles. Currently in England, the species only occurs within five large moss-dominated peatlands, one on Shropshire/ Wrexham border, one in Staffordshire, one in Chesire, and two in Cumbria.

1.3.3. UK historical record

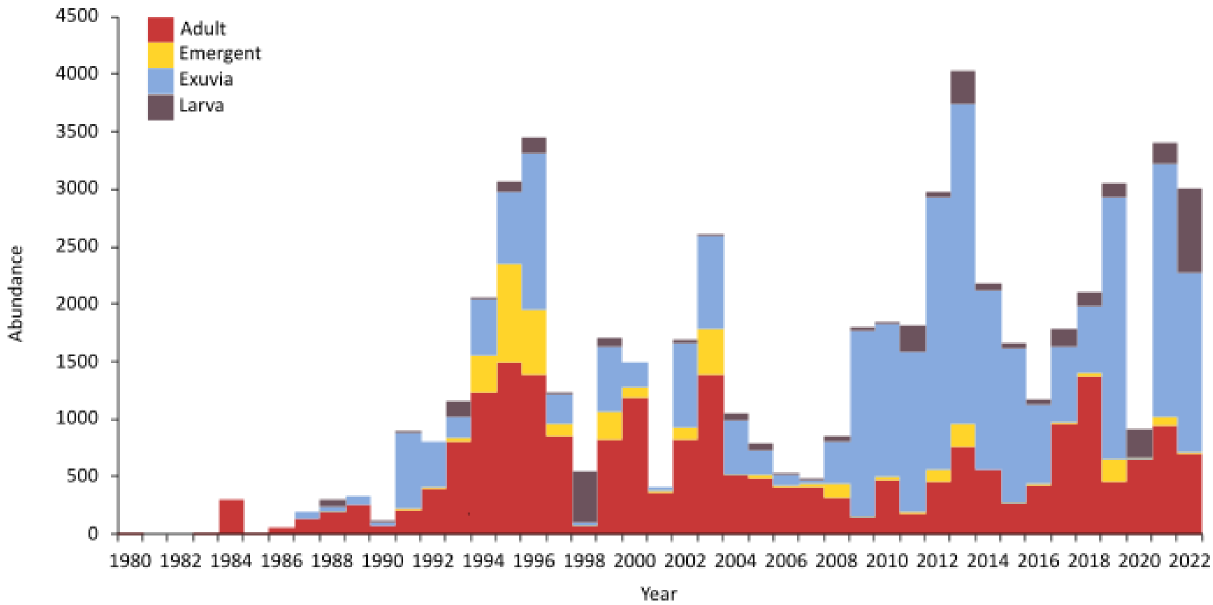

Figure 1.5 – Number of observations of L. dubia per year since 1980 in the UK (n= 58,118). Four different stages of L. dubia are represented: adult (flying), emergent, exuvia and larva.

The most recent historical compilation on the occurrence of *L. dubia* in Britain was done by Merritt et al. (1996). They reported that the first authenticated record was made in Yorkshire (Thorne Moor) in 1837. The species has never been reported in Ireland and in only one locality in Wales, near the English border. Its main historical strongholds were in Scotland (Inverness and Ross). In 1996, only seven breeding sites remained in England, six known sites having been lost between 1956 and 1976. Merritt et al. (1996) showed that the most significant decrease in the white-faced darter population occurred in 1975.

Although data are scarce prior 1980, records from the NBN Atlas database (NBN Atlas, 2023) (**Figure 1.5**) show that between the late 1980s and 2007, the apparent ratio of adults to exuviae was 2.4 (1σ: 1 to 5.6). This ratio fell to 0.4 (1σ: 0.1 to 0.9) after 2008. It is difficult to explain these changes. It could be that, in the last 40 years, there was a high mortality rate of emergent *L. dubia* and/or a low survival rate of adults. On the other hand, this could be due to a change in monitoring method; perhaps, historically only adults were typically recorded, whereas it has become good practice to record exuviae in more recent times. However, one thing that is certain is that the loss of habitat (i.e. loss of pools through drainage and afforestation), mainly caused by agricultural reclamation and a renewed interest in peat cutting in the 70's and 80's (Eversham, 1991), this is believed to the be the main cause for *L. dubia*'s population decline in the UK (Eversham et al., 1991).

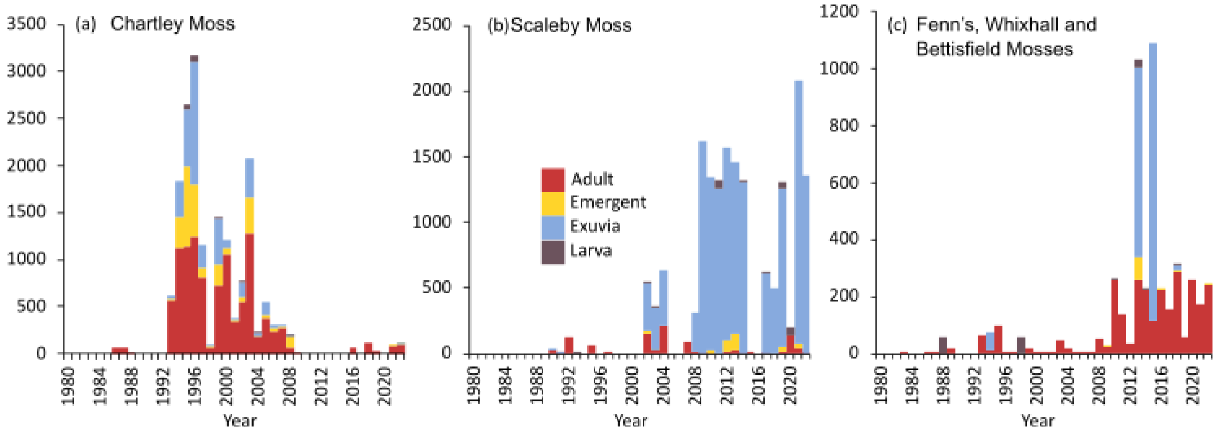

Figure 1.6 - Number of observations of L. dubia per year since 1980 in three English key natural sites: Chartley Moss (n= 15,579), Scaleby Moss (n= 16,843)) and Fenn's, Whixhall and Bettisfield Mosses (n= 4,859).

In England, the population dynamics of the *L. dubia* population can be assessed by looking at three key sites: Chartley Moss in Staffordshire, Scaleby Moss in Cumbria, and Fenn's, Whixall and Bettisfield Mosses on the Shropshire/Wrexham border (Beynon, 2001; Clarke, 2014; Davies et al., 2018a; Meredith, 2017). Peat cutting and/or drainage activities were present on these sites until the mid-20th century. At Chartley Moss (**Figure 1.6a**), there was a steady decline in adult *L. dubia* abundance from the mid-1990's to the near disappearance of the species in the late 2000's. At Scaleby Moss (**Figure 1.6b**), exuviae make up the bulk of the observations. Despite periodic increases in exuviae from the early 2000's, the number of adults recorded remained very low. The situation at Fenn's, Whixall and Bettisfield Mosses is different (**Figure 1.6c**). Restoration of the mosses in the mid-1990's correlated positively with the spread of the relict population (Davies et al., 2018a). This slow process took about 15 years since to see an increase in the *L. dubia* population.

These three examples illustrate the impacts different types of human activities (industrial exploitation or habitat rehabilitation) can have on the dragonfly population.

1.3.4. Previous UK reintroduction programs

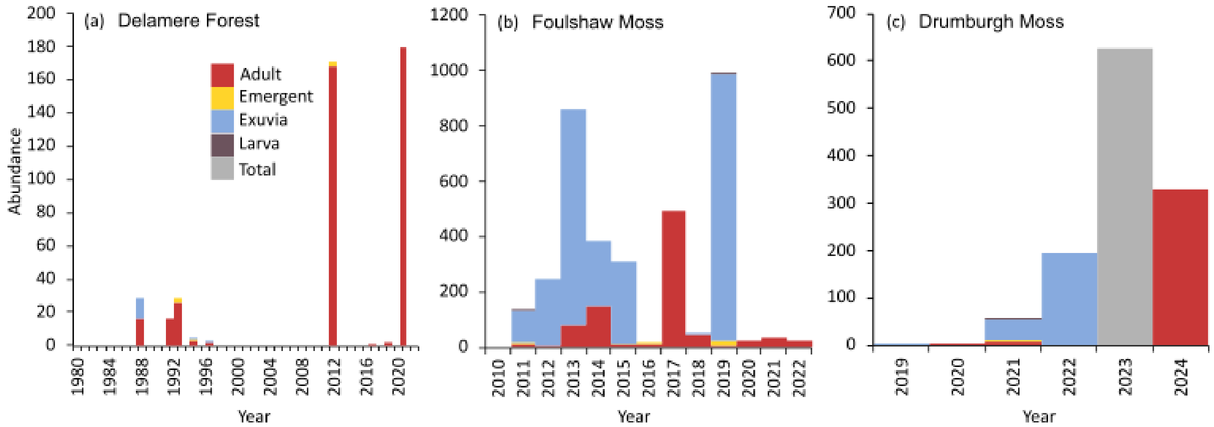

Figure 1.7 - Number of observations of L. dubia per year since 1980 in three English reintroduction sites: Delamere Forest (n= 15,579), Foulshaw (n= 16,843)) and Drumburgh Moss (n= 4,859). Note that for the year 2024 for Drumburgh Moss, survey have only been conducted in spring, therefore the number of observations is expected to be higher once the survey season is finished.

Although no reintroduction programs exist in Yorkshire yet, a couple of attempts at reestablishing *L. dubia* in previous hotspots have been performed throughout England, with different degrees of success. The presence of the species near Stone Edge (Derbyshire) between 1987 and 1993 is thought to be an unsuccessful attempt at introduction (Merritt et al., 1996).

Following peatland restoration in 2011, *L. dubia* was reintroduced in Delamere Forest, Cheshire in 2013 (Meredith, 2017). Since the late 1980's, the population of *L. dubia* in Delamere Forest was in steady decline (**Figure 1.7a**) and no more occurrences were recorded after 1997. Although challenging, three years of monitoring post-reintroduction showed many positives, notably successful oviposition (Adult in **Figure 1.7a**). It is still too early to assess the full impact of the reintroduction process. However, compared to other reintroduction programs (see below), it is so far less successful. Despite having spread to other sites in the forest, their number remain relatively low (max 180 adults for Delamere Forest compared to > 300 for Drumburgh Moss).

In Cumbria, between 2010 and 2013, the species was translocated from a donor site (Scaleby Moss, North Cumbria) to a receiving site (Foulshaw Moss, South Cumbria) (Clarke, 2014) (**Figure 1.7b**). Bad weather in the early years of the experiment considerably affected the reintroduction effort. However, there was a gradual increase in the number of exuviae between 2010 and 2015 and Clarke (2014) reported some improvement in the adult population in 2013 and 2014. 2017 and 2019 were marked by an increase in abundance in adults and exuviae respectively. Clarke (2014) also raised the issue of the ongoing degradation of the donor site (**Figure 1.7b**), possibly limiting future reintroduction attempts. This highlights the increasing need for peatland restoration to save some of the remaining (relatively) pristine habitats.

In 2019, the British Dragonfly Society (BDS) and Natural England have started a program to introduce *L. dubia* at Drumburgh Moss National Nature Reserve in Cumbria. Since then, the population has steadily increased (**Figure 1.7c**). In spring 2024, 328 individuals (half the total amount of 2023) were observed at the start at the survey season[3].

These different attempts are both guides to white-faced darter reintroduction practices and cautionary tales on the different aspects that might hinder the success of future programs. These examples, as well as other reintroduction programs and observations in natural sites were used to review the evidence and create a database to inform on the optimal habitat requirements. The database used and the associated references are available in the supplementary information.

[3] https://www.cumbriawildlifetrust.org.uk/news/rare-dragonfly-thrives-after-successful-restoration-peatbogs

1.4. DATABASE

The geographic distribution of the *L. dubia* population databases were built using data from the National Biodiversity Network (NBN) Atlas (NBN Atlas, 2023) and the Global Biodiversity Information Facility (GBIF, 2024).

The database used to identify the optimal habitat characteristics for the reintroduction of *L. dubia* was compiled from peer-reviewed literature (see supplementary information). We reported the number of *L. dubia* individual observed for different parameters (e.g. emergence support size; Sphagnum cover; water pH; water temperature; water conductivity; pool size; pool density; peat depth; number of predators). The number of *L. dubia* reported mainly corresponds to the number of observed adults. However, due to the limited amount of information, in two cases (Johansson & Samuelsson, 1994; Rychła et al., 2011), larvae and total number of Odonata individuals were also included.

1.5. RESULTS

1.5.1. Habitat size and structure

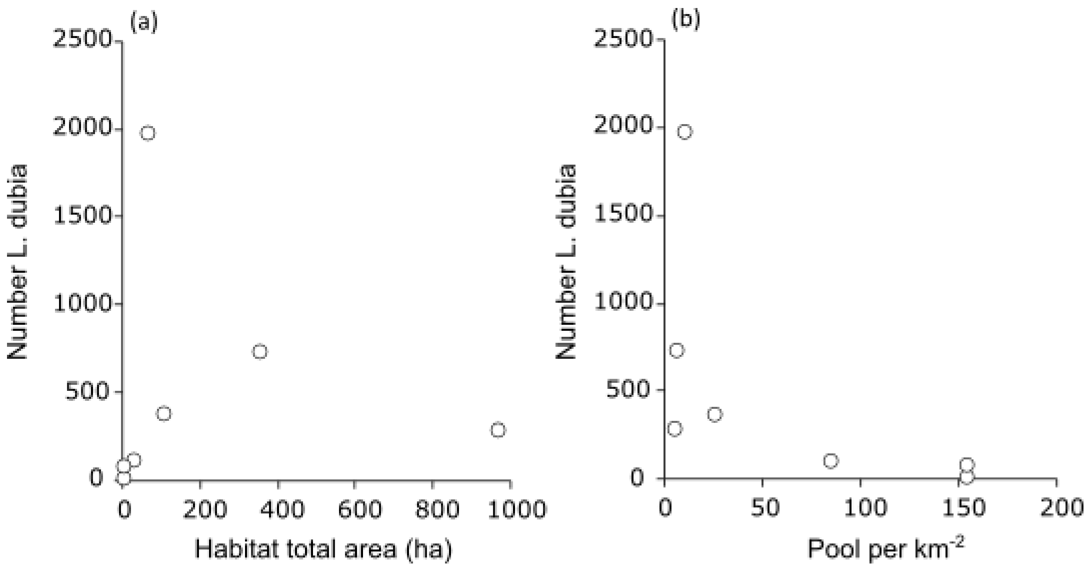

Figure 1.8 – (a) Number of L. dubia vs. habitat total size. The habitat total size corresponds to the size of the whole moss or peatland. (b) Number of L. dubia as a function of pool density.

The white-faced darter distribution correlates positively with the presence of peatlands in Eurasia[4], although in some instances, *L. dubia* can be found along lakeside shoreline (Boudot & Kalkman, 2015; Sushko, 2021) or in revegetated, wet sandpits (Theuerkauf & Rouys, 2001). The total habitat size of *L. dubia*, which includes the full extent of the peatland/forest cover, is quite variable. Our data compilation suggest that greater abundance in white-faced

[4] RICCARDO PRAVETTONI (2014) PEAT DISTRIBUTION IN THE WORLD. HTTPS://WWW.GRIDA.NO/RESOURCES/7553

darters is found for peatland <450 ha in size (**Figure 1.8a**). However, reported peatland areas are very scarce in the literature. A better constraint can be placed using the *L. dubia* flying range. It has been recorded that *L. dubia* can travel up to 40 to 300 m from their pond to their roost (Beynon, 1995, 2001; Clarke, 2014; Meredith, 2017), which translates into an effective (i.e. breeding, feeding, roosting) circular habitat size of 1 to 28 ha (for one given pond). One of the decisive factors for the presence of *L. dubia* therefore seems to be the density of pools with a given area. Although more studies on more sites would be needed to confirm this trend, available data suggest an increase in *L. dubia* individuals for a pool density up to 50 per km^2 (Beynon, 2001; Clarke, 2014; Davies et al., 2018a; Dolný et al., 2018; Meredith, 2017) (**Figure 1.8b**). Considering the effective circular habitat size, we suggest that minimum and maximum number of pools are 4 and 199 per km^2 respectively. Old peat cuttings are good breeding ground for *L. dubia* (Clarke, 2014; Meredith, 2017; Merritt et al., 1996). They form steep-sided pools which can hold a significant volume of water and have been revegetated with floating rafts of *Sphagnum* mosses.

The vertical structure of the habitat is mainly controlled by the vegetation. Although it can withstand high wind speeds (Beynon, 1995; Sushko, 2021), most *L. dubia* hotspots are found in relatively sheltered sites (Adamović et al., 1996; Beynon, 1995; Clarke, 2014; Meredith, 2017). *L. dubia* tends to favour an open moss habitat with a composite vegetation typical of high-quality raised bog (e.g. NVC M18 – *Erica tetralix, Sphagnum papillosum* and a low proportion of *Calluna vulgaris*) (Boudot & Kalkman, 2015; Clarke, 2014; Davies et al., 2018b).

L. dubia is a “percher” species and requires the presence of scattered tall perches in its habitat to warm up and feed (May, 1991). Sunny perches up to 2m in height within the vicinity of the pools are used by adults to bask and by males to patrol their territory (Beynon, 1996). *L. dubia* tends to favour woody perches with a pale coloured bark (e.g. birch, alder). As the bushes and trees can be more than 50 m away from the nearest pool, a heterogeneous, in-between-ponds shrub and tall plant cover (e.g. heather, bracken) within 0 to 3m from the pools can make a temporary shelter. This provides a place for *L. dubia* to rest (Beynon, 1995) and hide from potential avian predators (Clarke, 2014; Meredith, 2017). Some shrubs can also act as perches when overhanging the water and can create favourable microclimates (Beynon, 2001).

The presence of nearby tree cover (e.g. pine and birch) is also an essential aspect of the habitat structure (Clarke, 2014). There is a direct positive relationship between the *L. dubia* population and the presence of coniferous woodlands within the vicinity of Sphagnum-rich bog pools in Scotland (Geary & von Hardenberg, 2021). The distance between the pools and the tree line can exceed 100m (Meredith, 2017). These bog forests are usually used for feeding and for overnight roosting to avoid low nocturnal temperatures (Merritt et al., 1996; Sushko, 2021). The tree density and the degree of shading it creates provide shelter during the pre-reproductive period (Kalniņš, 2012).

1.5.2. Ponds

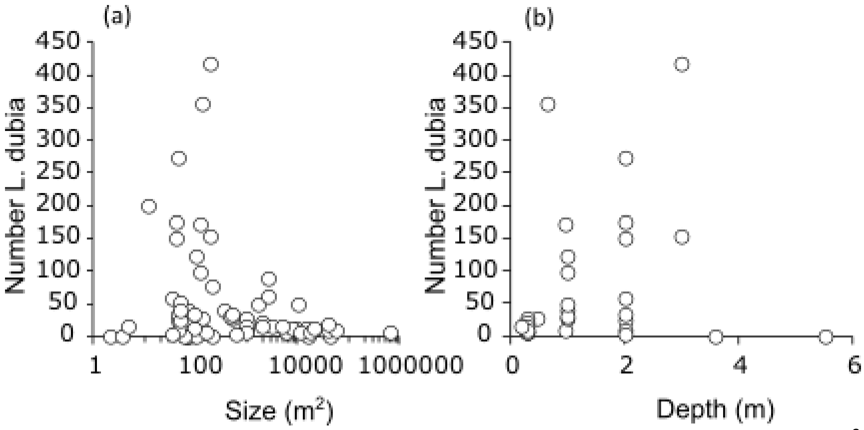

Figure 1.9 – Pond geometry. (a) Number of L. dubia observed as a function of the surface area (m^2). The dataset was fitted with a cubic model. The ideal pool size varies between 50 and 150 m^2. (b) Number of L. dubia observed as a function of the pond depth (m).

Within a given pond, the presence and abundance of *L. dubia* are directly related to the geometric characteristic of the pool and the chemical and physical properties of the water. *L. dubia* is found associated with waterbodies of all sizes, from very small pools (~2 m^2) (Beynon, 2001) to lakes (>10^4 m^2) (Adamović et al., 1996; Johansson & Samuelsson, 1994; Rychła et al., 2011). Greater abundance (more than 100 observed individuals) is found for pool sizes between 10 and 110 m^2 (**Figure 1.9a**). White-faced darters also seem to prefer relatively shallow water, from 0.3 m deep on the edge of large waterbodies (Johansson & Samuelsson, 1994) to 0.5-3 m deep in bog pools (Beynon, 2001; Clarke, 2014) (**Figure 1.9b**). Data suggest that a water depth up to 3 m is good for *L. dubia*, although some dragonflies have also been recorded near ~14m deep waterbodies (Beynon, 2001).

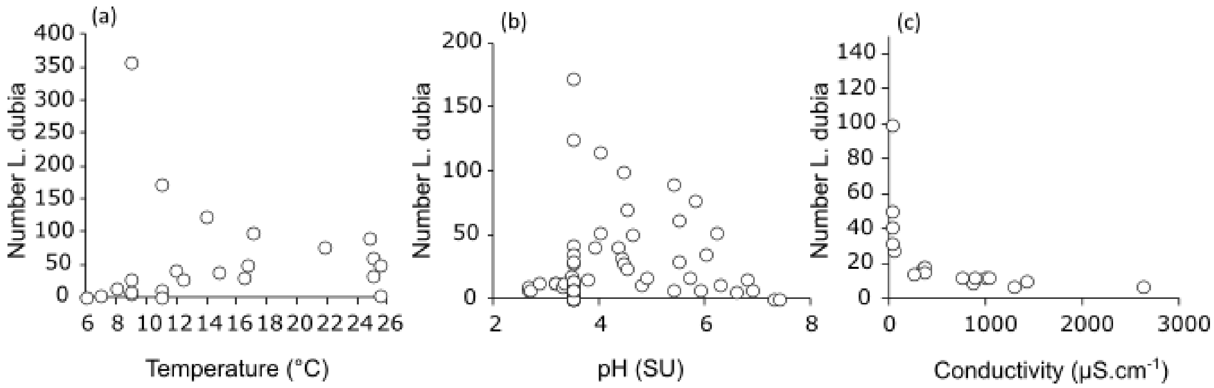

Figure 1.10 – Pond water properties: (a) Number of L. dubia vs. temperature (°C). (b) Number of L. dubia vs. pH (SU). (b) Number of L. dubia vs. electrical conductivity (µS.cm1).

L. dubia is a cold-adapted species, and sunshine and temperature variations do not significantly affect its distribution (Sushko, 2021), although it might favour unshaded pools (Boudot & Kalkman, 2015). In our database, we observed an increase in the abundance of *L. dubia* with water temperatures up to 10 °C. Above this temperature, the number of observed dragonflies remains relatively constant (**Figure 1.10a**). Although we are limited by the size of the dataset, there might be a decrease in *L. dubia* population above 26 °C. This would be in agreement with observations that described a larvae population decline above

30 °C (I. Suhling & Suhling, 2013). 26°C to 28°C has also been shown to be the optimal temperature for larvae growth, 0.35 $mm.day^{-1}$ at 27.5°C compared to 0.01 $mm.day^{-1}$ below 20°C (F. Suhling et al., 2015).

L. dubia are found in acidic and oligotrophic waterbodies with a range of water pH, from 2.6 (Rychła et al., 2011) to 7.4 (Adamović et al., 1996) (**Figure 1.10b**). Our database indicates that higher numbers of individuals are usually found in waters where pH varies between 3 and 6 (Beynon, 1995; Meredith, 2017; Rychła et al., 2011; Sushko, 2021).

The compiled database shows that water electrical conductivity (EC) correlates negatively with the abundance of *L. dubia* (Buczyńska & Buczyński, 2019; Meredith, 2017; Rychła et al., 2011) (**Figure 1.10c**). *L. dubia* favours bog pools as they result from the accumulation of nutrient-poor rainwater, which translates into a low EC. Natural bog pools have an EC of 15 to 103 $\mu S.cm^{-1}$ (Turner et al., 2016). A higher EC tends to favour other Odonata species (Rychła et al., 2011).

1.5.3. Flora

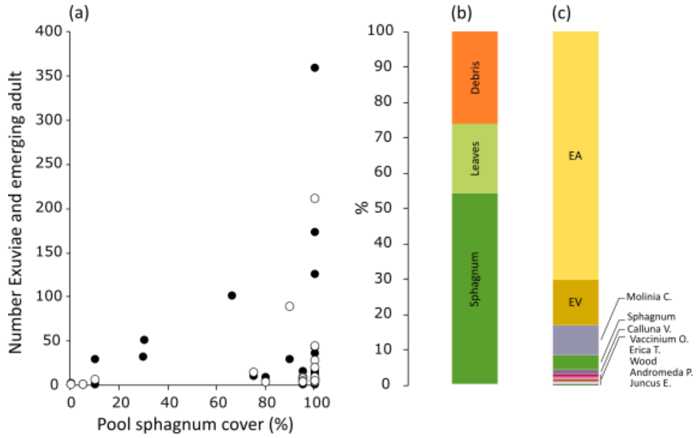

Figure 1.11 – Peatland flora associated with the presence of Leucorrhinia dubia. (a) Pool sphagnum cover vs. number of observed exuviae (white dot) and emerging adults (black dot). (b) Preference substrates for larvae (Henrikson, 1993). *(c) Preference of emergence support (EA: Eriophorum angustifolium – common cotton grass; EV: Eriophorum vaginatum – hare's-tail cottongrass)* (Meredith, 2017).

The vegetation structure and diversity within the pools and their direct surroundings are key factors in controlling the abundance of *L. dubia* in peatlands. Typical bog vegetation surrounding *L. dubia*-rich ponds consists of *Sphagnum* cuspidatum, sundews, cottongrass, cross-leaved heather, common heather, cranberry, bilberry and a lesser amount of rushes and scrub/trees (Beynon, 1995; Boudot & Kalkman, 2015; Dolný et al., 2018). Such vegetation is characteristic of a very healthy, near-pristine bog. The presence of rushes (e.g. Juncus effusus) might be detrimental to the establishment of *L. dubia* (Ervin & Wetzel, 2002). Rushes are symptomatic of nutrient-rich raised-bogs that have revegetated after intense agricultural activity. Therefore, areas dominated by rushes are less suitable for the recolonisation of some Odonata species (Krieger et al., 2019).

In central European mountain ranges, *L. dubia* is confined to *Sphagnum cuspidatum*-rich bog pools while other Odonata species tend to thrive where moss is absent (Adamović et al., 1996). The data we compiled suggest that there is a positive correlation between the number of exuviae and emerging adults and the pool *Sphagnum* cover (**Figure 1.11a**) ((Beynon, 2001; Buczyńska & Buczyński, 2019), with a minimum requirement of 30% to 70% cover. This floating *Sphagnum* layer provides a range of ecological advantages for *L. dubia*. An experiment conducted in acidified lakes in Sweden indicated that *L. dubia* favours *Sphagnum* substrates to lay its eggs, with 54% of larvae observed in the floating bog moss, compared to 26% on debris (e.g. needles, twigs) and 20% on leaves (Henrikson, 1993) (**Figure 1.11b**). The *Sphagnum* mat covering the pools is an important food source for Odonata larvae as more organic material and nutrient accumulates in this Sphagnum-rich environment (Henrikson, 1993). It might also act as a heat sink, favouring the development of larvae (Beynon, 1998), hence being a preferred site for oviposition, along with cottongrass growing through the water (Beynon, 1995, 1996). Finally, the dense *Sphagnum* cover serves as a shelter for the larvae against predation (Henrikson, 1993). In the lowlands, abundant floating hook-moss (*W. fluitans*) can occasionally provide the same ecological services as *Sphagnum cuspidatum* (Merritt et al., 1996). In central Europe, other types of Sphagnum (*S. scorpioides* and *S. contortum*) can also fulfil a similar role (Adamović et al., 1996).

Meredith (2017) showed that *L. dubia* preferentially use common and hare's tail cottongrass as emergent supports (*E. angustifolium* and *E. vaginatum*) followed by *Molinia* grass and *Sphagnum* (**Figure 1.11c**). Similar observations were made in Chartley Moss (Beynon, 1995, 2001). The nymphs can climb between 2 cm to 12 cm above the water surface (Beynon, 1995; Meredith, 2017).

1.5.4. Fauna

The presence of other animals in the white-faced darter habitat can have a range of positive and/or negative effects. *L. dubia* was found cohabitating with other dragonfly species such as *S. danae* (black darter), *A. juncea* (common hawker), *P. nymphula* (large red damselfly), *L. sponsa* (emerald damselfly), *A. caerulea* (azure hawker) and *S. artica* (northern emerald) (Beynon, 2001; Merritt et al., 1996). *L. quadrimaculata* (four spotted chaser) has a territorial behaviour towards *L. dubia*. However, both species tolerate each other by flying at different heights (Clarke, 2014).

A greater population of white-faced darter correlates positively with waterbodies with low or no fish present. An average of 2 larvae has been recorded for fish-present waterbody, compared to 62 larvae recorded for fish-absent pond or lake (Henrikson, 1988; Johansson & Brodin, 2003; Petrin et al., 2010) (**Figure 1.12a**). In Sweden and Finland, *L. dubia* have long abdominal spines which give them a tactical evasive advantage to resisting fish predation in breeding pools (Flenner et al., 2009; Johansson, 2017). This feature is lacking in white-faced darters from other European countries which makes them less suited to the presence of such predators (Henrikson, 1988). Most of the occurrences of *L. dubia* have been reported around waterbodies of pH ~ 4. Where *L. dubia* have the defensive abdominal spines, they can survive in fish-present waters, and therefore can live in the widest pH range, 5 to 8 (**Figure 1.12b**); whereas, *L. dubia* lacking this adaptive feature (including in Britain) are restricted to a lower, acidic pH range which allows them to evade fish, since fish typically cannot breed below pH 6. Similarly, the great crested newt (*Triturus cristatus*) is also a potential predator for dragonflies. However, despite being found in acid and alkaline waterbodies (pH 4.4 to 9.5), newts usually breed in pools with a pH above 6 (Gustafson et al., 2009).

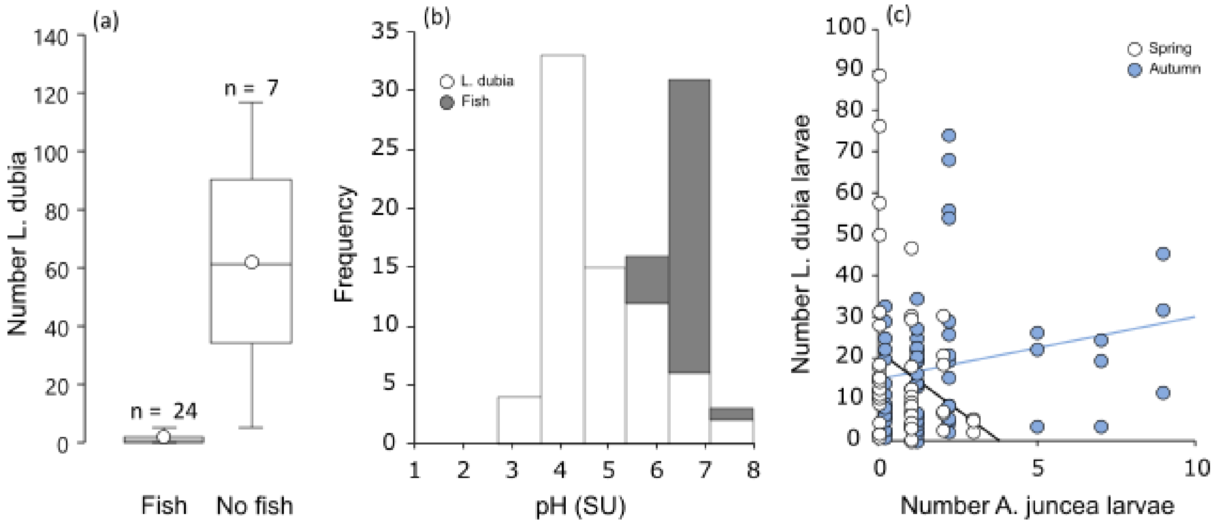

Figure 1.12 – Relationship between predators (fish and A. juncea) and L. dubia. (a) number of L. dubia observed in fish-present and fish-absent waterbodies. (b) Water pH (SU) in fish-present waterbodies compared to water pH in waterbodies where L. dubia was observed. (c) Number of L. dubia larvae as a function of the number of A. juncea larvae in both Spring and Autumn. Black (Spring) and blue (Autumn) are linear fits.

Finally, *L. dubia* larvae and nymphs can also be preyed upon by other dragonflies and beetle larvae (Beynon, 1995). In some cases, the presence of zooplankton can reduce the pressure on *L. dubia* (and other larvae) as it creates an alternative food source for predators, such as *A. juncea* larvae (common hawker), in the autumn (**Figure 1.12c**) (Johansson, 1991). In spring, the lower zooplankton availability could explain the higher preying behaviour of *A. juncea* larvae and the decrease in number of *L. dubia* larvae (**Figure 1.12c**).

Once emerged, birds are the main aerial predators. Snipe, hobby, house sparrow, crow and grey heron are among the species that have been recorded feeding upon white-faced darters (Beynon, 1995; Clarke, 2014; Meredith, 2017). Other dragonflies such as *A. imperator* (Emperor Dragonfly) can also prey on *L. dubia* (Clarke, 2014). However, the presence of other species of large-bodied dragonflies might also limit the bird predation on *L. dubia* (Meredith, 2017). Other invertebrates (e.g. spiders and ant) might also predate *L. dubia* as they emerge from the exuvia and are at their most vulnerable (Beynon, 1996).

1.5.5. Summary

Using the data presented above, we can place quantifiable estimates on the average habitat parameters for *L. dubia* (supplementary information). Due to the variable size of the dataset and the skewness of some distribution, we used a combination of log and square root transformation methods and error on the means to estimates the optimal habitat parameters. The confidence interval for the different parameter is 1σ. Results are displayed in **Table 1.1** and summarised in **Figure 1.13**.

*Table 1.1 – Optimal quantifiable habitat parameters for L. dubia. *Optimal geographic location in the UK.*

	Average value	Confidence interval (±1σ)	Size of dataset
Altitude (m)*	146	31-261	1065
Latitude (N°)*	55.980699	54.01447-57.94693	1065
Size of raised bog (ha)	100	33-300	7
Peat depth (m)	5.4	3.1-7.7	5
Pool size (m^2)	70	20-240	41
Pool depth (m)	1.0	0.5-1.92	21
Pool density (pool/km^2)	10	4-26	6
Flying distance from pool (m)	142	44-240	5
Perches height (m)	1.25	0.5-2	4
Pool *Sphagnum* cover (%)	81	49-112	36
pH for *L. dubia*	4	2.9-5.2	72
pH fish-rich waters	6.5	6-7	30
Temperature (°C)	12.5	7.3-19.1	23
Electrical conductivity (µS/cm)	370	82-1659	17
Emergence support (cm)	8	4-12	11

In the UK today, *L. dubia* tends to reside in Northern England and Scotland and has the potential to colonise raised bogs of 33 to 300 ha in size found from near sea level to about 250 m in altitude.

In an ideal bog habitat for *L. dubia*, the peat depth is more than 3 m (Turner et al., 2016). A standard pool network consists of about 1 m deep waterbodies occupying an average surface area of 70 m^2 spread at a density of 10 pools per km^2. Annual water pH and temperature mean values are 4 and 12.5°C respectively in the UK. EC is highly variable. Bog pools with EC below 100 $\mu S.cm^{-1}$ might be best for *L. dubia* (Turner et al., 2016).

The overall vegetation of the site should correspond to that of an active raised bog, restored or near-natural. *L. dubia* is extremely dependant on the presence of *Sphagnum cuspidatum or* similar bog-pool sphagnum species (Henrikson, 1993). *Sphagnum* can cover more than 2/3 of the surface of the pool and the presence of cottongrass provide good emergence support. In the in-between-pool vegetation cover should have a mix of hummocks and shrubs up to 1.25m in height (e.g. C. vulgaris), placed 0 to 3 m from the edge of the waterbodies. The presence of trees (e.g. pine, birch) is essential for *L. dubia* habitat. White-faced darters can thrive in open space and the understorey of native coniferous forest (Geary & von

Hardenberg, 2021). To that end, the roosting tree line should be no further than 250 m from the middle of any pools.

The population of *L. dubia* is strongly negatively correlated by the presence of large water predators (e.g. fish, newts). *L. dubia* can coexist with other species of dragonfly but they can also be detrimental to its reestablishment (e.g. predation by hawker larvae).

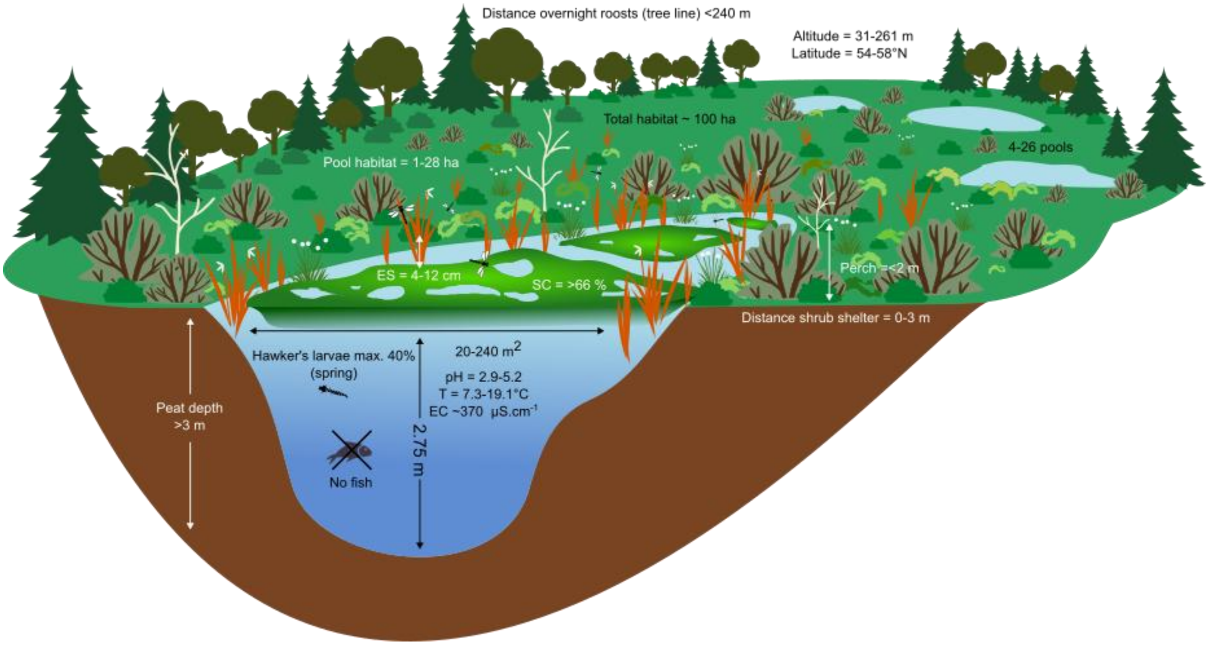

Figure 1.13 – Ideal habitat characteristics for L. dubia. EC: Electrical conductivity; ES: emergence support; SC: sphagnum cover in the pools; T: temperature.

1.6. DISCUSSION

1.6.1. Limitation of the dataset

Like all data aggregators, the data held in National Biodiversity Network (NBN) Atlas (NBN Atlas, 2023) and the Global Biodiversity Information Facility (GBIF, 2024) are not evenly distributed among years, locations, observers, and taxa. Therefore, the information that can be retrieved from them mainly depends on how regular data are collected and filled. Although it might be good indication of the white-faced darter habitat and its distribution in time and space, there distribution might also be an artifact of where people are more likely to go and find them. Declining habitat suitability could also mean that more remote areas might have become refuges for *L dubia* and their *de facto* “normal” habitat.

The list of parameters gathered in our database is as exhaustive as permitted by the current literature on white-faced darters. The size of the dataset for each parameter is highly variable indicating that some parameters are more robust than others. Further reintroduction programs will help to fill gaps in our knowledge and refine this database overtime.

1.6.2. Current and future threats in the UK

The future of the *L. dubia* population in the UK will depend upon a series of interdependent parameters that can be easily pressured by human activities and environmental changes. Unfortunate, the majority of peatlands in England/Britain are not in a healthy state and currently do not meet the requirements to sustain a healthy population of *L. dubia*.

Drainage for farming purposes and peat-cutting activities have turned a significant part of the UK's peatland into inhospitable, fragmented habitats for *L. dubia* (Natural England, 2020), characterised by a low water table, drier vegetation and oxidizing bare peat areas (Berry & Butt, 2002). Although peat extraction is in decline (Alexander et al., 2008), a legal ban is yet to be enforced. Peat extraction results in further lowering the water table of the bog, turning the landscape effectively into an ecological wasteland, as it becomes unsuitable for peatland flora and fauna. The UK horticultural industry is the main consumer of peat with three million cubic meters extracted each year[5], the bulk of the market being amateur gardeners. In the 1990's, a set of government policies were put in place to phase out peat extraction (Whitfield et al., 2011). A bill for the prohibition of the sale of horticultural peat is currently being debated in Parliament with the aim to end the retail of peat by 2030. Until then, the use of sustainable alternatives relies on voluntary initiative.

Peat cutting activities feed into the threat of climate change, which remains the principal challenge faced by *L. dubia* and peatland ecosystem in general. For instance, in Delamere Forest, the unpredictability of the weather (i.e wetter and colder conditions than average) have pushed *L. dubia* to delay their emergence to early summer (Meredith, 2017). A longer time spent in the breeding pools might expose them to a greater risk of predation (Johansson, 1991) and hinder their reproductive cycle. On the other hand, drier and warmer summers might have the potential to affect the water table and the temperature of the bog pools. The latter is critical for the development of larvae as mortality rate increases significantly above 30°C (I. Suhling & Suhling, 2013). The overall change in climatic conditions also pushes other dragonfly species northwards (e.g. *C. erythraea* – Scarlet darter), which might then compete with *L. dubia* for territorial gain and/or prey on them (I. Suhling & Suhling, 2013).

Climate models for North Yorkshire show that the area faces an average temperature increase of 2.3 °C by 2040-2069 (**Figure 1.14a**). Within error, rainfalls in 2040 are expected to be similar to that of the 1991-2020 period (Data and model from the Met Office©). However, they could be occasionally higher in autumn, spring and winter due to severe downpour episodes. An average temperature increase of 2.3 °C would increase the chances of extreme precipitation (> 20mm/h) by 23% (Kendon et al., 2023)(**Figure 1.14b**). In the UK, droughts are likely to be more severe and protracted in future (Parry et al., 2024). In North Yorkshire the Drought Severity Index (DSI) could double by 2040 (**Figure 1.14c**). These significant environmental changes are going to put additional pressure on existing *L. dubia* populations and potentially hinder reintroduction efforts. It is therefore imperative to support the creation of resilient landscapes to mitigate the effects of global warming.

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[5] [ARCHIVED CONTENT] Consultation: Reducing the horticultural use of peat in England

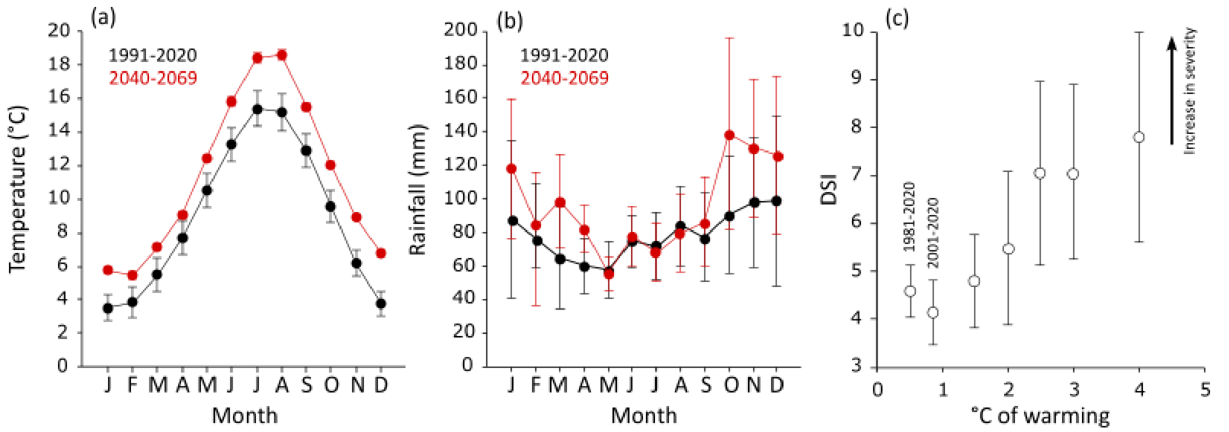

Figure 1.14 – Effect of climate warming in North Yorkshire. (a) Monthly temperatures (°C) between 1991 and 2020 and projection for 2040-2069. (b) Monthly precipitation (mm) between 1991 and 2020 and projection for 2040-2069. (c) Drought Severity Index (DSI) vs. the degree of global warming (°C). Data and model from the Met Office©.

1.6.3. Implications for future L. dubia translocation work

The *L. dubia* population in the UK is in decline. It has only a few remaining fragmented strongholds. With the threat of climate change, these isolated populations become increasingly vulnerable. Population improvement then depends upon the application of Lawton's principles of species connectivity: more, bigger, better and joined-up sites within the landscape (Lawton, 2010). *L. dubia* do not usually migrate far from their ponds. Therefore, they need connected corridors (landscape or linear) between lots of core habitats to ensure the species can become resilient and self-sustaining in the UK. It is important to promote the spread of the UK *L. dubia* population as it is relatively isolated from other European populations. It is only genetically closely related to the Swiss and French *L. dubia* populations (Johansson et al., 2017b, 2017a).

Translocations in the past have been relatively successful (see *Section 1.3: Previous UK reintroduction programs* above) (Clarke, 2014; Meredith, 2017). These reintroduction efforts have provided a wealth of information about what habitats *L. dubia* requires for successful recolonisation. Therefore, if this species is to become established in North Yorkshire and to survive in the UK in general, reintroduction programs need to upscale their efforts and be more ambitious, looking not just to preserve the current strongholds as these are too isolated, but to create resilient and connected regional landscapes.

Rewetting and revegetating initiatives are essential parts of the reintroduction effort as pool complexes are essential to provide connectivity throughout the bog. Through restoration, improvement of the state of peatlands can provide core areas and stepping stones for the spread of bog species, including *L. dubia*. The network of *Sphagnum*-rich, acidic bog pools (i.e. from the artificial types: pools formed behind blocked ditches and specifically created bog pools, and to the natural: natural bog pools formed on pristine peatlands) allows for *L. dubia* to spread and colonise its different parts, insuring population persistence through the years (Davies et al., 2018b; Kharitonov & Popova, 2011). In the three main UK receiving sites, reintroduction was preceded by peatland restoration work and the creation of bog pools. We pulled together data on three reintroduction sites (i.e. Delamere Forest; Foulshaw and Drumburgh Moss) to show the impact of restoration on the overall reintroduced white-faced darter population. The current data suggests that a significant gap (> 5 years) should be left between restoration and reintroduction (**Figure 1.15**). Longer duration allows the peatland to recover some its necessary ecological services. Attempts at reintroduction within a couple of years after restoration is met with a weaker, delayed response in *L. dubia* population increase.

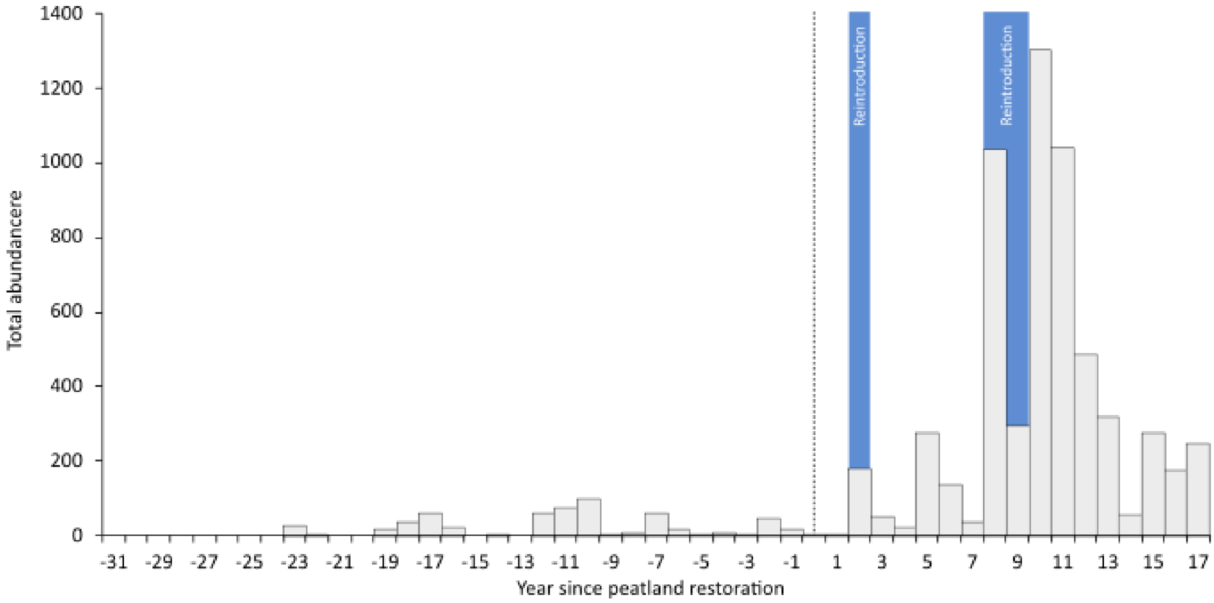

Figure 1.15 – Total abundance of L. dubia (different stages) observed since peatland restoration (i.e. ditch blocking and creation of new pools). The vertical blue bars indicates when L. dubia was reintroduced. Data from Delamere Forest, Foulshaw and Drumburgh Moss.

1.6.4. Towards reintroduction in North Yorkshire

The current Dragons in the Dales project led by Yorkshire Peat Partnership aims to find suitable sites for the creation of new *L. dubia* strongholds. In North Yorkshire, Swarth Moor is one such lowland raised bog, which has undergone peat restoration, which is being investigated for its habitat suitability as a recipient site for *L. dubia* reintroduction[6] (Swindles et al., 2016). This site is close to other nearby lowland raised bogs (Austwick Moss, Lawkland Moss and Malham Tarn Moss), which could potentially help the species to spread. Although Malham Tarn Moss (Turner et al., 2014) lies outside the altitude-latitude range for the UK, the number of pools and tree cover present on the site could make it a viable candidate.

These three sites are close to each other with Austwick and Lawkland Mosses 5km way from Swarth Moor, and Swarth Moor 8km away from Malham tarn Moss. Some white-faced darters have been previously recorded ~8km away from their breading site (Clarke, 2014). Therefore, there is potential for corridor to promote the spread of *L. dubia* in North Yorkshire.

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[6] McMaster, J. & Bodycote, J. (2024) **Swarth Moor, Yorkshire Dales National Park, Dragonfly Habitat Enhancement Plan – Yorkshire Peat Partnership**

The Dragons in the Dales project could open new opportunities for further reintroduction programs in other part of Yorkshire (e.g. the Humberhead Levels, Thorne Moor, East Yorkshire) and beyond.

1.7. CONCLUSION

In this literature review, we compiled numerical data on *L. dubia* from Europe and the UK to define what likely represents their average habitat conditions. It is abundantly clear that the survival, growth and spread of the *L. dubia* population in Great Britain depends upon a set of parameters which are intrinsically linked to the state of our peatlands in the UK. Creating resilient landscapes through peat restoration (i.e. rewetting and revegetating) is essential in mitigating the effect of climate change on the biodiversity they support.

We have provided information to help peatland practitioners adapt some of their restoration specifications and timeframe for creating best suitable environment for *L. dubia* while delivering effective peatland restoration. Although our study only targets one species of dragonfly, peatland restoration should also benefit other invertebrates, birds and mammal species. It is our view that improving biodiversity is as important an outcome of restoration as limiting flooding and carbon emissions, and this type of evidence gathering work might need to be conducted more often in the future.

Reintroductions of *L. dubia* in the UK have had mixed results. Although the number of individuals has increased, it is still difficult to evaluate the longevity of the population. Nevertheless, evidence suggests that to help a *L. dubia* colony establish itself and thrive in a new area, its habitat needs to bigger, better and more joined up.

Data should be collected in systematic way and shared widely to refine reintroduction protocols of *L. dubia* going forwards. In the next section of this report, we look at implementing the findings from this literature review and surveying a target lowland raised bog site, Swarth Moor, for its suitability for a white-faced darter reintroduction to Yorkshire.

1.8. SUPPLEMENTARY INFORMATION

For supplementary information, please see appendices.

PART 2: HABITAT SUITABILITY SURVEY PRE-WORKS

2.1. INTRODUCTION TO SECTION

In Part 1, we have researched the literature and presented the known habitat requirements of the white-faced darter, *L. dubia*.

In Part 2, we aim to apply these habitat requirements to assess a target site in Yorkshire for its suitability for white-faced darters. The target site is Swarth Moor, a lowland raised bog in North Yorkshire (see Figure 2.1).

We first carried out a series of habitat surveys to collect data on these factors: 1) vegetation structure, 2) peat depths, 3) pH, 4) electrical conductivity, 5) water depths, 6) water flow, and 7) nitrate and phosphate levels.

We then describe how we carried out an aquatic invertebrate survey to collect data on these factors: 1) aquatic invertebrate abundance and diversity as prey, and 2) presence of fish and amphibians as predators. (For Habitat Enhancement Plan, see Appendices)

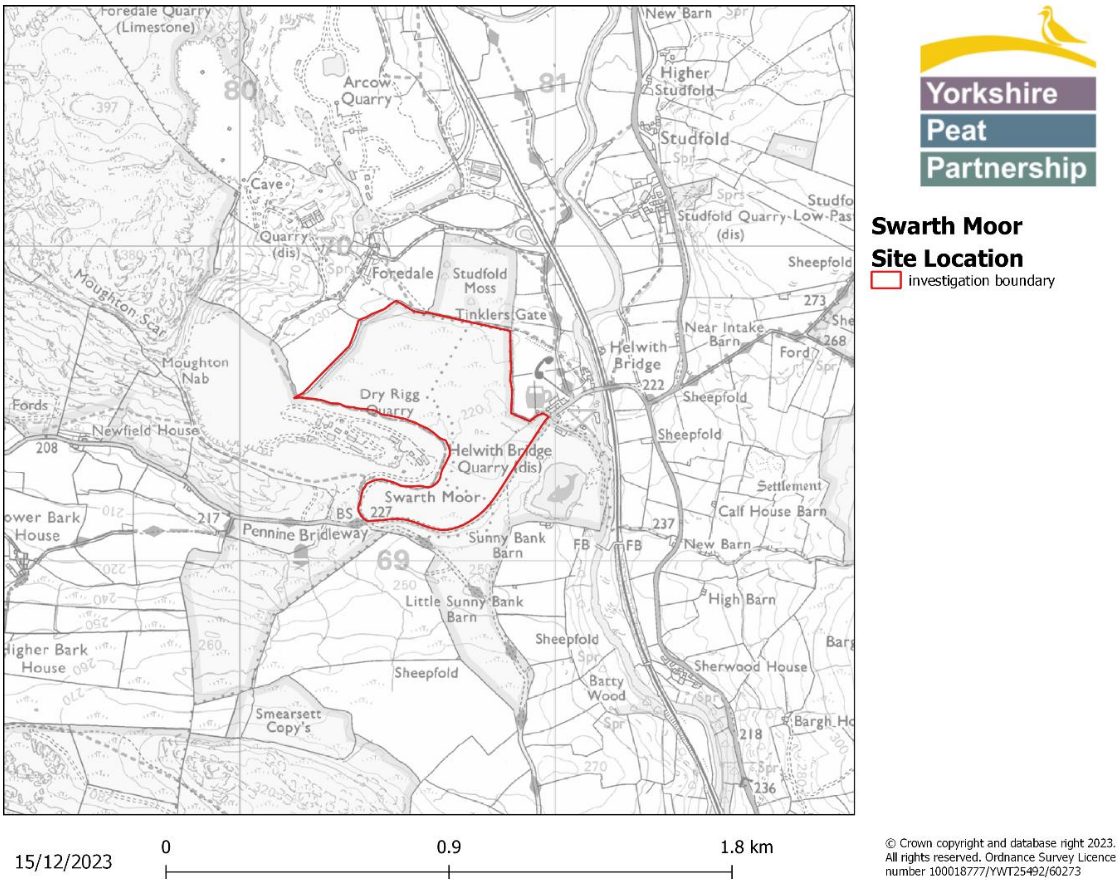

Figure 2.1 – Site Location of Swarth Moor

2.2. BACKGROUND

Swarth Moor is situated within the parishes of Stainforth and Austwick in the west of the Yorkshire Dales National Park. It covers an area of approximately 29 hectares and the OS Grid Reference for the centre of the site is SD806695 (Figure 2.1).

Swarth Moor lies within Swarth Moor SSSI. The condition of the Raised Bog is designated by Natural England as being ‘unfavourable - recovering’, and the southern Fen area designated ‘favourable’.

Swarth Moor is a lowland raised bog boarded by a large quarry, farmland and a road. It is much smaller now than its historical extent and has historically had drainage cut into it. There has been little management beyond grazing which has all but ceased.

In 2020, Swarth Moor benefited from a rewetting project. This involved cell-bunding in a grid pattern across the centre of the bog to slow the flow of water escaping the peat dome (see Figure 2.2). This is working well and seems to be increasing the cotton grasses coverage and decreasing the *Molinia* grass coverage. Three ponds were created as mitigation for the great crested newts on site, shown as three small ponds in the south of the site (Figure 2.2).

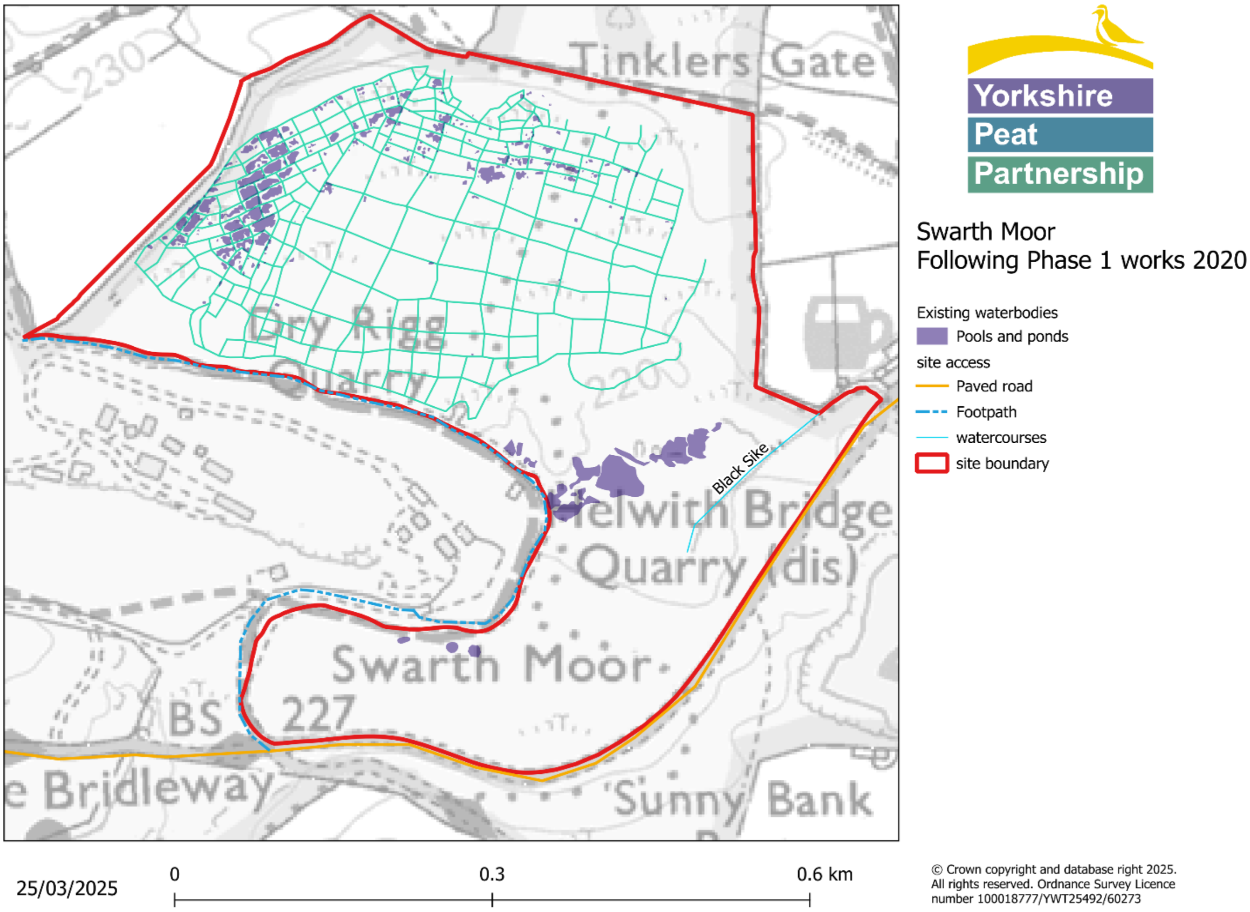

Figure 2.2: Swarth Moor cell-bunding and waterbodies, following the phase 1 restoration works in 2020.

There is no livestock grazing on site but there are several roe deer frequently seen on site.

The site is managed by Natural England, with local volunteers, to control the scrub that is increasing on the site.

In 2023 the fen area was surveyed and a hydrological restoration plan written through funding by Natural England. The work on the fen area was carried out in autumn 2024 also with funding from Natural England, overseen by Yorkshire Peat Partnership.

2.3. METHODOLOGY

Swarth Moor was surveyed by Yorkshire Peat Partnership between 5th September to 20th December 2023 in order to carry out an initial Habitat Suitability Assessment for *L. dubia*.

The survey which was broken down into 4 parts as follows:

2.3.1. UAV survey

The site was fully surveyed on the 05/09/2023 using a DJI Mavic 3 Enterprise equipped with a 4/3 CMOS 20MP RGB sensor at a resolution of 2.5cm/per pixel. An orthomosaic and digital surface model (DSM) were generated from the data using PIX4D Mapper photogrammetry software.

The resulting data was used to investigate the vegetation structure of the site, in particular to look at: proximity of waterbodies to 'tree roosts', and proximity of waterbodies to 'shrub shelter', pond surface vegetation, pond emergent vegetation, and the watershed i.e. water flow paths on the site.

2.3.2. Pre-survey

The Pre-Survey is the initial desk-based survey using aerial photographs and data from the UAV survey. Target areas for the habitat field survey were mapped out around existing waterbodies and scrub patches (Figure 2.3). The centre of the raised dome was generally avoided during survey activities because cell-bunding had already been successfully implemented here for restoration of the raised bog hydrology.

2.3.3. Habitat field survey

Information was recorded with the Mergin Maps software onto a smart tablet about the vegetation species coverage within the existing waterbodies and the cover within an 5m buffer of the waterbodies. Other data recorded were peat depth, water depth, waterbody size and the overall vegetation community. Previous data from the survey delivered by Yorkshire Peat Partnership in April 2023 was consolidated with the data from this survey to give full peat depth maps.

Additionally, measurements were taken in areas of standing water for: pH, electrical conductivity (EC), nitrate NO_3 levels, and phosphate PO_4 levels.

The data gathered is used in the final stage of the survey to determine the type of work required to enhance the dragonfly habitat on the site.

2.3.4. Post-survey

With the field survey data uploaded to QGIS, Voronoi polygon maps and proximity heat maps were created to show how the biotic (e.g. vegetation structure) and abiotic factors (e.g. acidity, water depth, watershed) changed across the site.

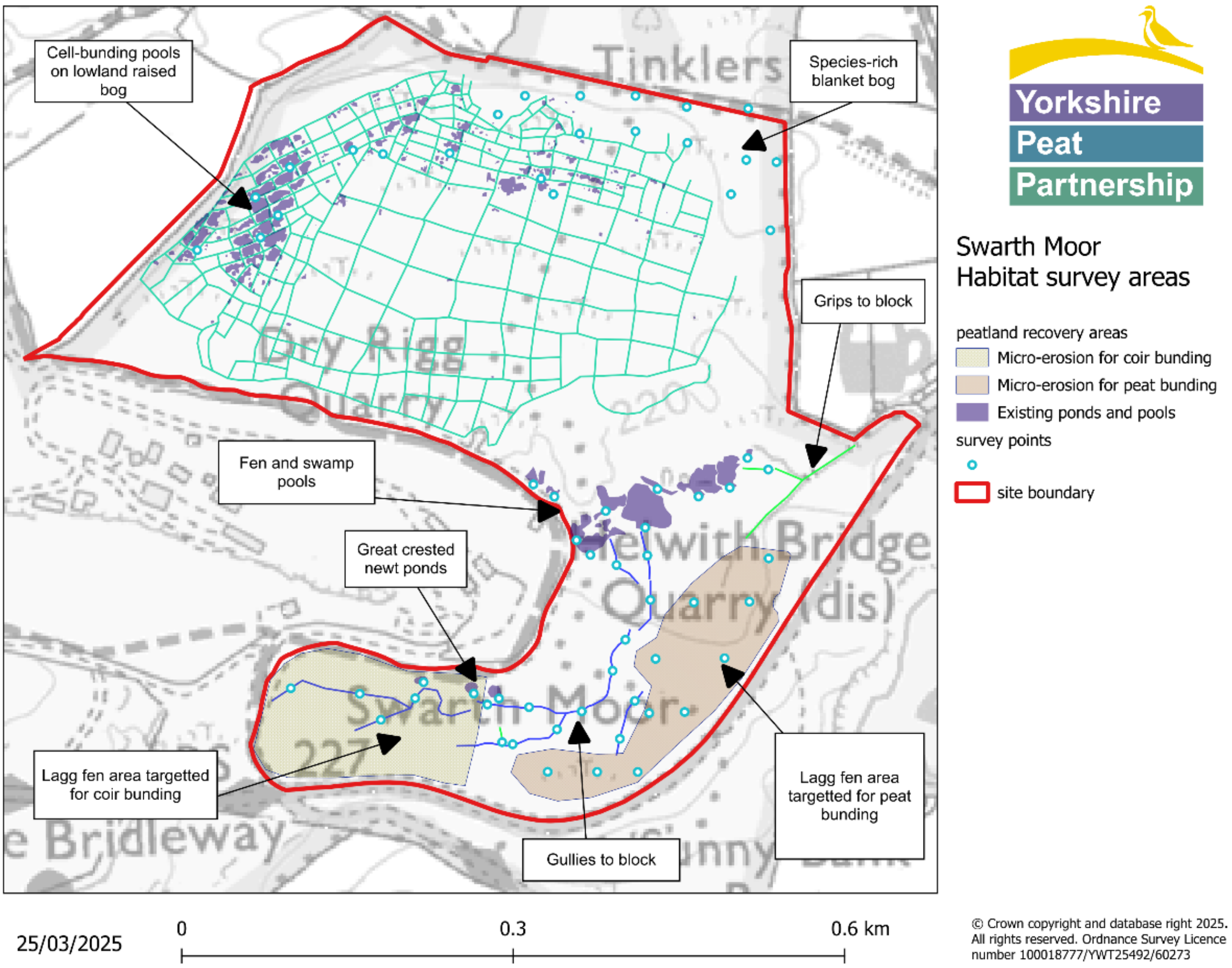

Figure 2.3 - Habitat suitability survey areas

2.4. HABITAT FIELD & UAV SURVEY 2023

2.4.1. Vegetation Structure

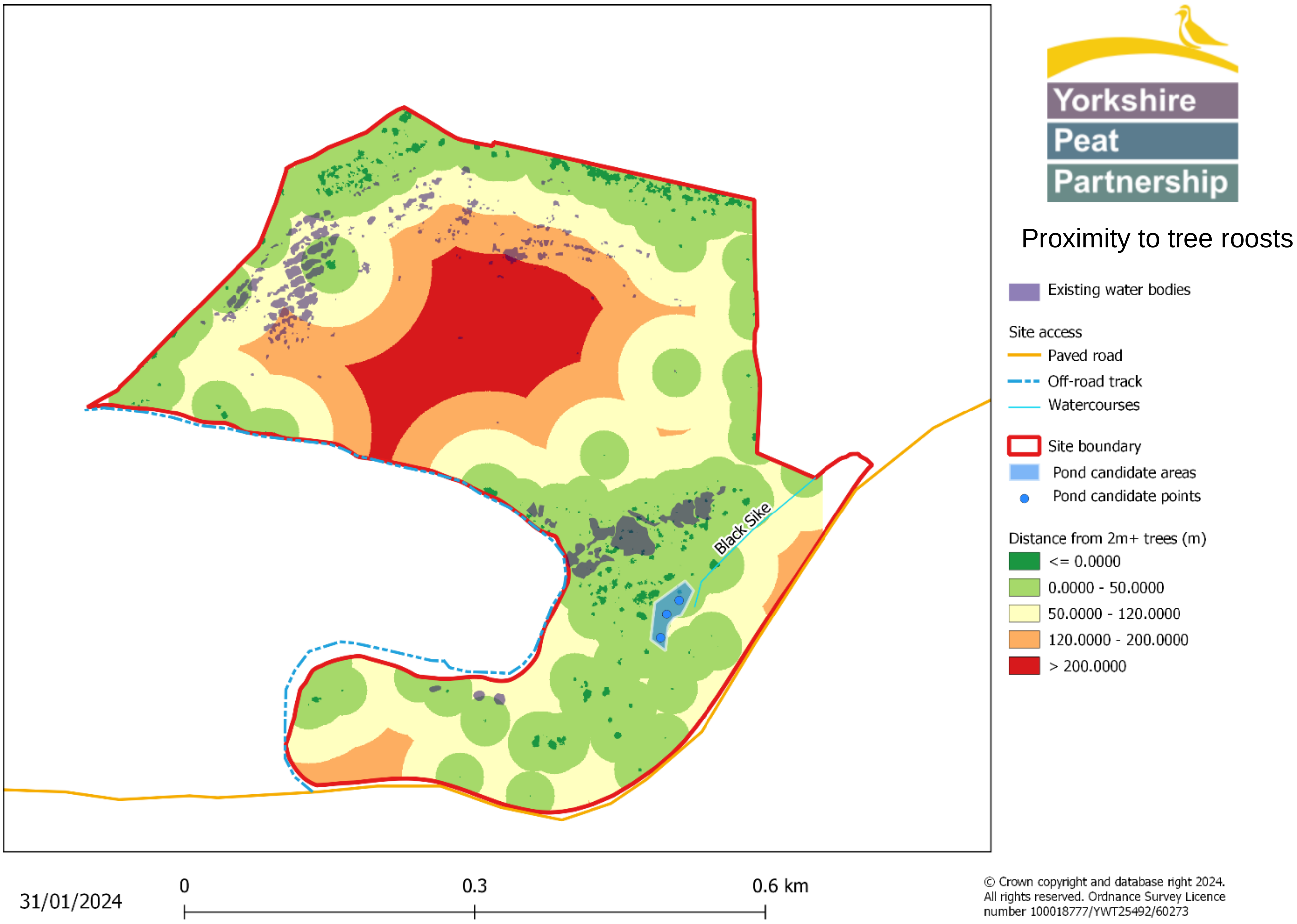

Figure 2.4 - Proximity to 'tree roosts' over 2m in height

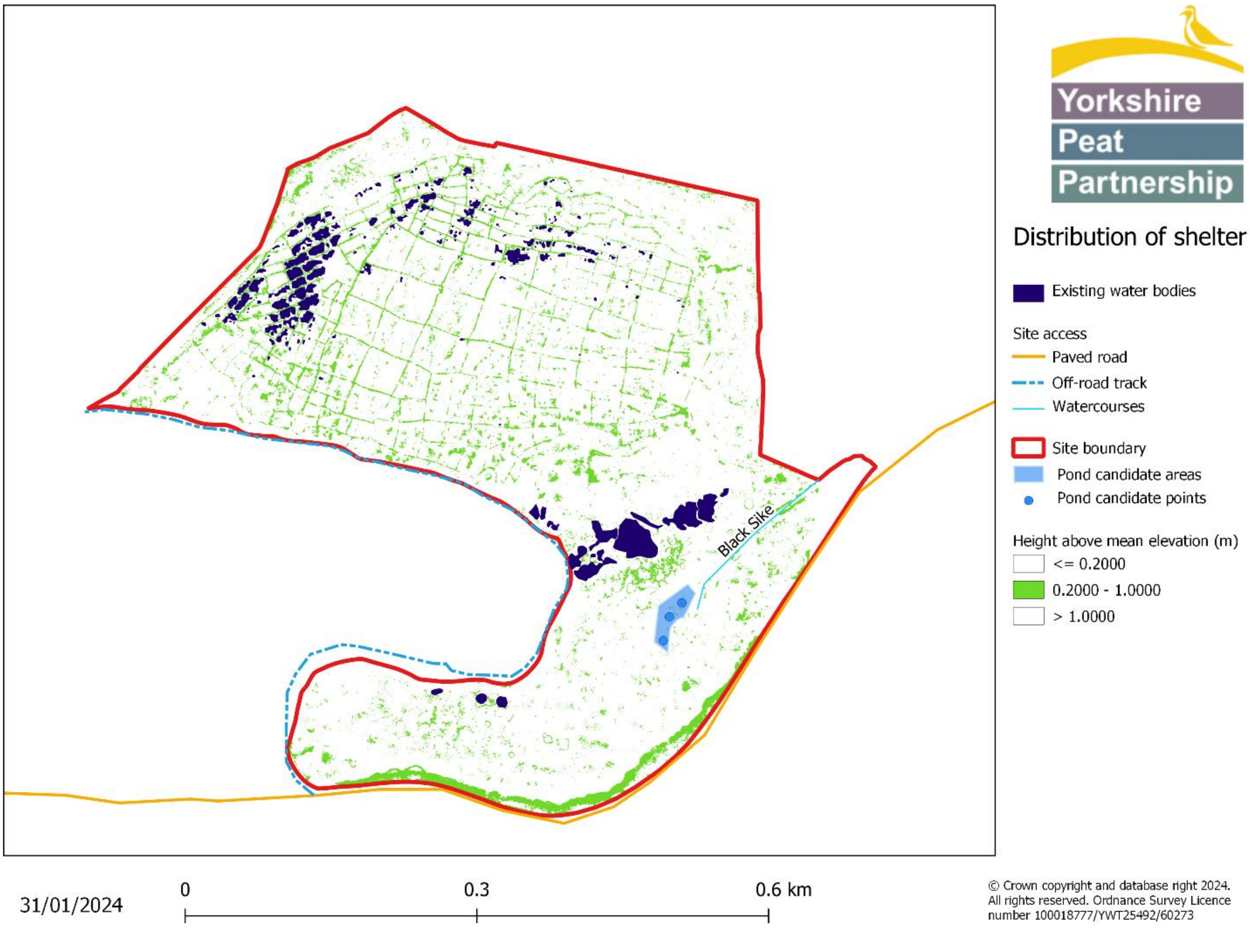

Figure 2.5 - Distribution of 'shrub shelter', vegetation 20-100cm in height

Figure 2.4 shows that all existing waterbodies have some 'tree roosts' (as defined as trees/scrub over 2m tall) surrounding and/or close to them.

Figure 2.5 indicates that 'shrub shelter' (defined as vegetation between 0.2-1.0m tall) is spread across the site with greater density in some specific areas, which are likely to be more suitable.

L. dubia prefers to breed in waterbodies within 50m of tree roosts, but they have been observed traveling up to 120m between water and roost areas. An emerging dragonfly's maiden flight to shrub shelter, on the other hand, can be a short distance away up to 2-3m. Newly emerged dragonflies 'tenerals' on their maiden flight need to fly towards shelter quickly, to prevent avian predators (e.g. Reed buntings) from catching tenerals on their first flight.

2.4.2. Peat Depths

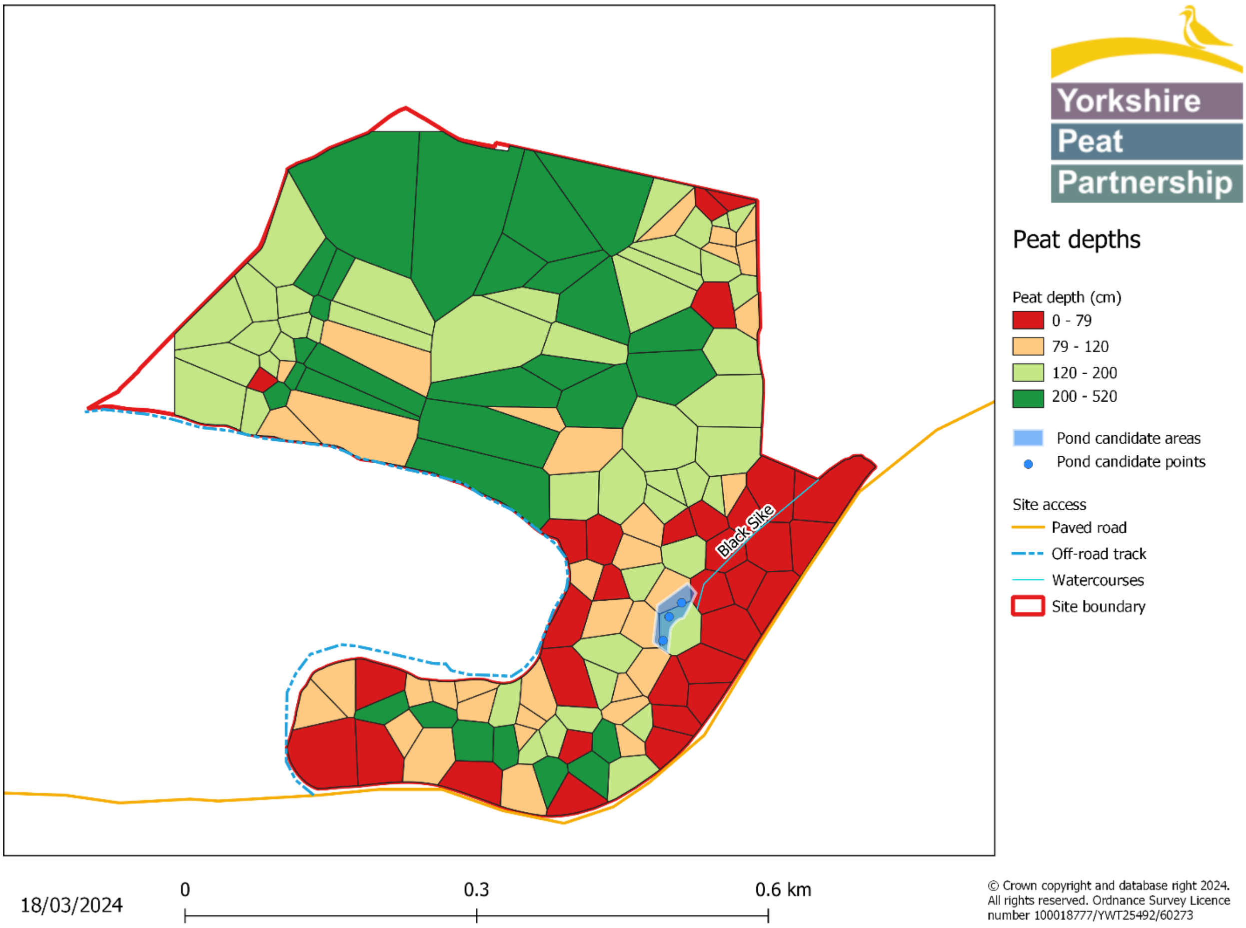

Figure 2.6 - Peat depths, extrapolated from field points using Voronoi polygons.

The greatest peat depth found on site was 5.2 meters in the top centre of the dome, with the average peat depth being higher on the northern half of the site. The British Dragonfly Society recommends providing ponds at least 1m deep for *L. dubia*, although they have successfully breed in pools and ditches of 47cm in depth in Chartley Moss in Staffordshire with 67cm being the most ideal in this paper (T. Beynon, 2001); more research is needed to accurately map the depths at which this species prefers to breed. Our research and the expert advice we were given led us to view that the ponds need to be at least 70cm deep with a peat substrate base. Therefore, the peat depth needs to be at least this deep to create suitable pools.

2.4.3. pH

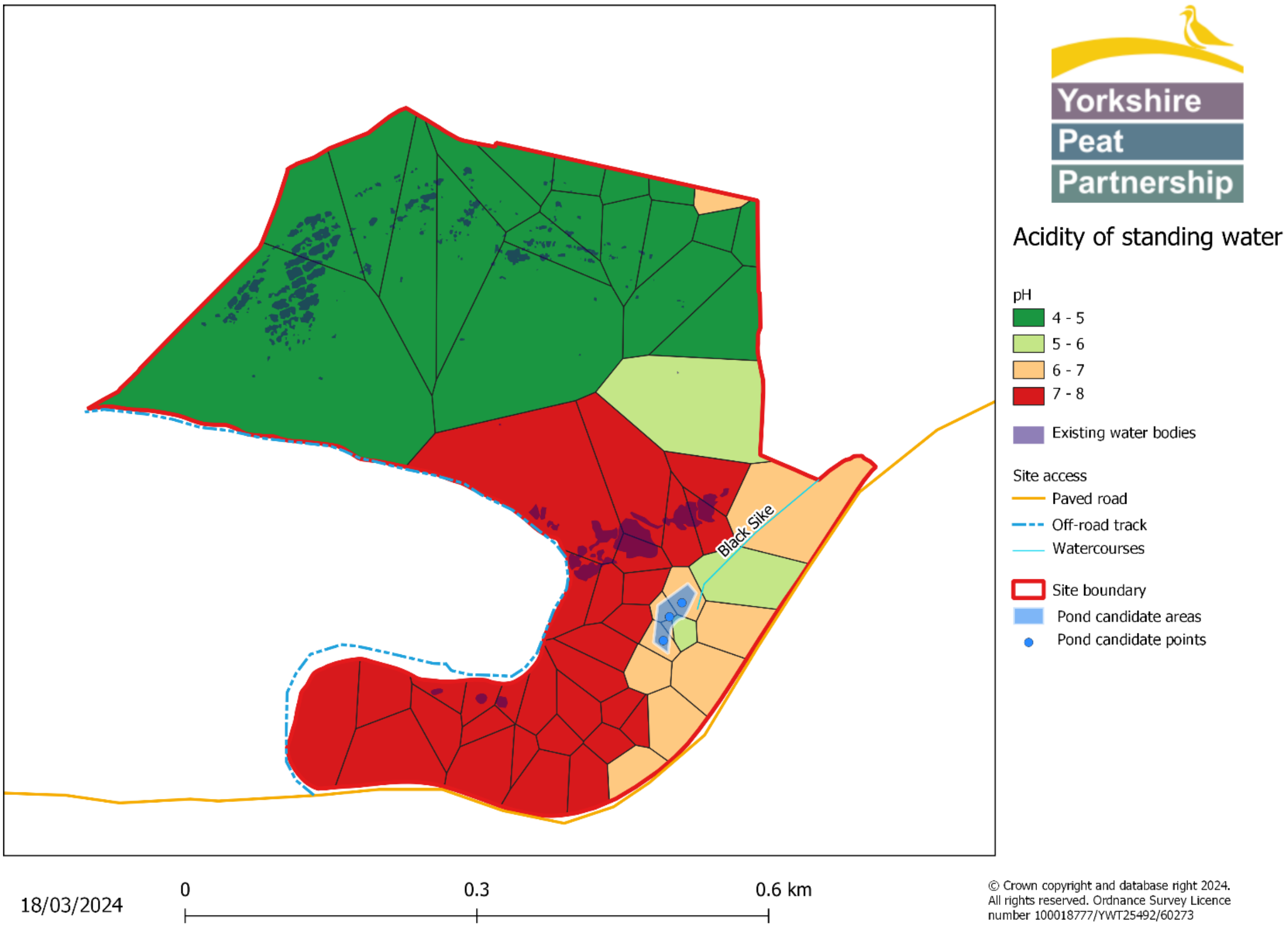

Figure 2.7 - pH of standing water, extrapolated from field points using Voronoi polygons.

As demonstrated in Figure 2.7 there's a significant difference in pH between the northern and southern half of the site. Acidity was greatest in the north at between 4.0-6.0 pH and lowest along the southwest edge at 6.0-8.0 pH. On a healthy raised bog, the pH is below 6.0. It is natural for an area of lagg fen to be more base-rich than the neighbouring bog but the extent of it across the southern half of the site is likely to be influenced by the neighbouring land use and the watercourse running south-west to north-east across the south of the site.

L. dubia can tolerate pH levels as low as 3, whereas most potential predator species (such as fish or newt efts) cannot survive and/or reproduce lower than 5. Additionally, great crested newts favour ponds above pH 6. *L. dubia* requires *Sphagnum cuspidatum* for oviposition, a species with the ability to lower the pH of the water around it by manipulating ions – any ponds created would benefit from *S. cuspidatum* inoculation.

The ideal pH for the pond area would be <6.0, but 6-7 is acceptable because fish have not been recorded on site and with *S. cuspidatum* inoculation any newt species should be deterred.

2.4.4. Electrical Conductivity

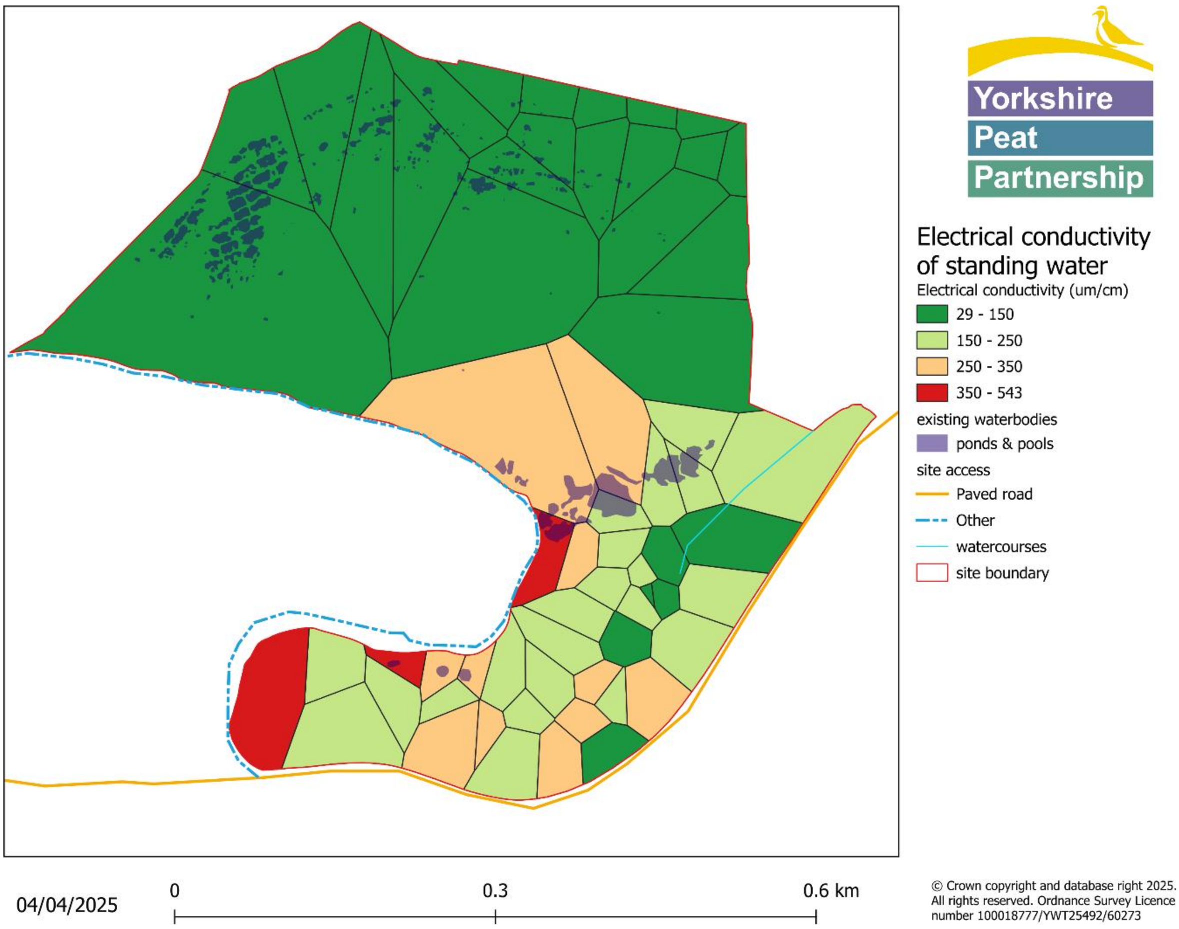

Figure 2.8 - Electrical conductivity of standing water, extrapolated from field points using Voronoi polygons.

Electrical conductivity (EC) is lowest around the mound of the raised bog, which is to be expected from an ombrotrophic bog, i.e. minerals and nutrients only enter the habitat through precipitation; likewise, the EC is relatively higher in the fen area because it is minerotrophic: i.e. nutrients are also brought in from ground water. All of the areas surveyed are within the range that *L. dubia* can be found successfully breeding; a conductivity below 250 µS/cm is a good target for ponds, above 600 µS/cm are not ideal for ponds. The highest EC recordings were measured closest to the edge of the quarry bank, so this could indicate that some polluting ionic compounds are reaching the site from the quarry, or mineral-rich groundwater naturally seeping into the fen.

By measuring the EC across the site, we have been able to use it as a proxy of measuring nutrient levels in the water. The vegetation *L. dubia* is closely associated with can be outcompeted by more vigorous species when nutrient levels are high, so for them, lower is better.

2.4.5. Water depths

Waterbody (as labelled in Figure 2.3)	Water depth (cm)	
	Range	**Mean**
Cell-bunding pools on lowland raised bog	10-40	28.3
Fen and swamp pools	10-65	36.25
Great crested newt ponds	40-60	50
Lagg fen area for coir bunding	8-20	13.25
Lagg fen area for peat bunding	0	0
Gullies to block	0-65	24.32
Grips to block	5-35	20
Species-rich blanket bog	0-10	5

Table 2.1 - Water depths of existing waterbodies

The waterbodies already in existence on the target site range from a minimum of 5cm of shallow water, up to 65cm deep in the fen pools.

N.B. Grips and gullies to be blocked were also included in the 'water depths' recorded, although at the time of the survey they had not been blocked and so would not be classed as permanent waterbodies, however the planned restoration would result in standing water as potentially permanent waterbodies.

As discussed in the literature review, the average pond depth in the literature for *L. dubia* presence is 1.0m, with a confidence interval (±1σ) of 0.5-1.92m, and so a depth of above 0.5m would be acceptable, and above 1.0m would be ideal.

However, the existing waterbodies with depth 65cm did not have the correct abiotic conditions, therefore new ponds would need to be constructed to meet the pond depth and abiotic requirements.

2.4.6. Watershed

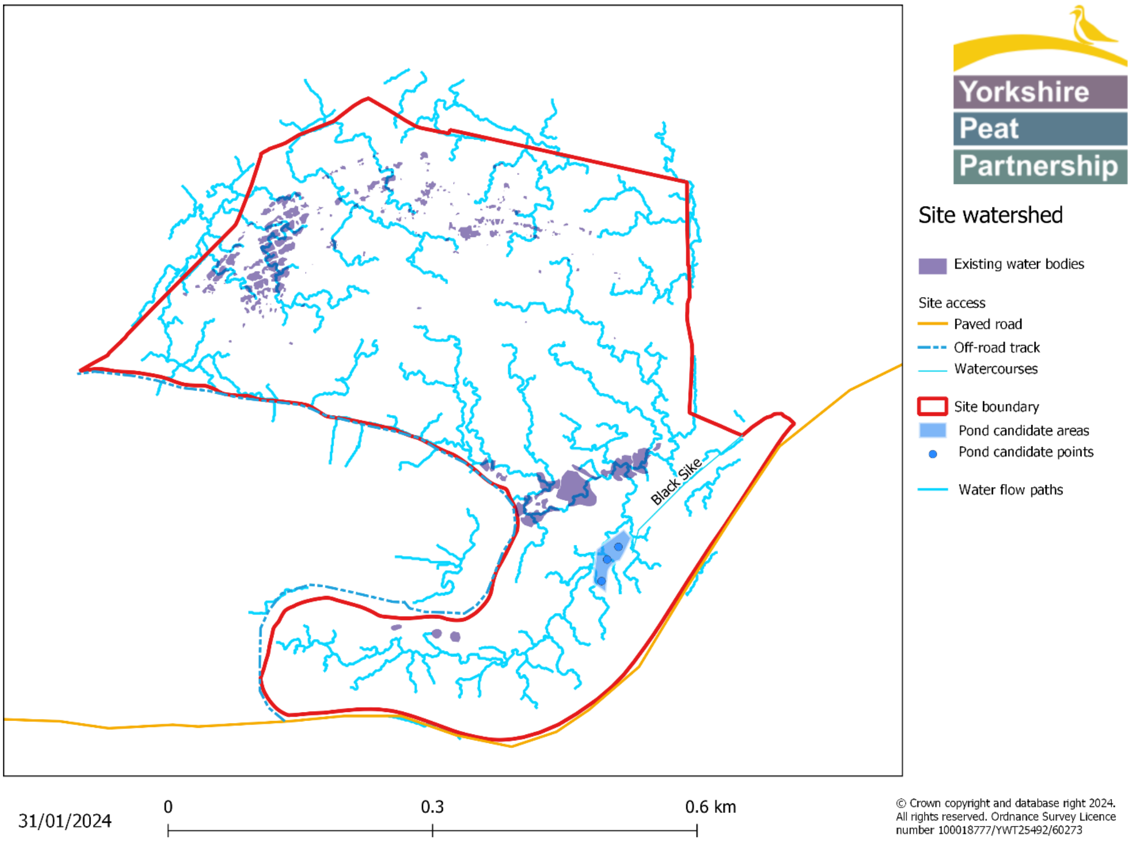

Figure 2.9 - Swarth Moor watershed

The flow paths mapped from UAV data show that the northernmost part of the site is hydrologically isolated from the rest of the site, which is to be expected with a raised dome. This separation offers an explanation to the significant contrasts in pH and EC figures between the areas. A bog receives all its water from precipitation (i.e. rainwater fed) and so is described as 'ombrotrophic'.

The rest of the site will be receiving rainwater, but it also receives groundwater which will be seeping out of the ground, enriching the southern 'lagg fen' and the central 'fen pools' with mineral deposits, creating different vegetative communities. These fens are described as 'minerotrophic'.

Currently, most of the water on site flows into the drain named "Black Sike". This has resulted in the water table of the lagg fen and peat dome being lowered, and consequently purple moor grass *Molinia* has spread across the site as it prefers drier conditions.

The flow paths confirm that the grips and gullies are all draining into Black Sike and off-site. The peat restoration work planned will block the grips and gullies, including Black Sike, and thus will slow the flow of water and raise the water table. A higher water table is good for the health of the bog, fen, and lagg fen, and will also be good for maintaining permanent waterbodies on site for aquatic wildlife including dragonflies.

2.4.7. Nitrates and Phosphates

When deciding on a location for a wildlife pond, it is important to consider pollution levels which may hamper the success of invertebrate life establishing in the new ponds. Nitrate and phosphate are commonly used as measures of pollution. We used test kits for nitrate NO_3 and phosphate PO_4 which use a colour chart to qualitatively determine the concentration of the chemicals in parts per millions (ppm). According to Freshwater Habitats Trust which produce advice on installing and maintaining ponds, levels of nitrate at less than 0.5ppm and phosphate at less than 0.05ppm are considered to have no pollution from these chemicals, so these are the levels we would target for installing our ponds.

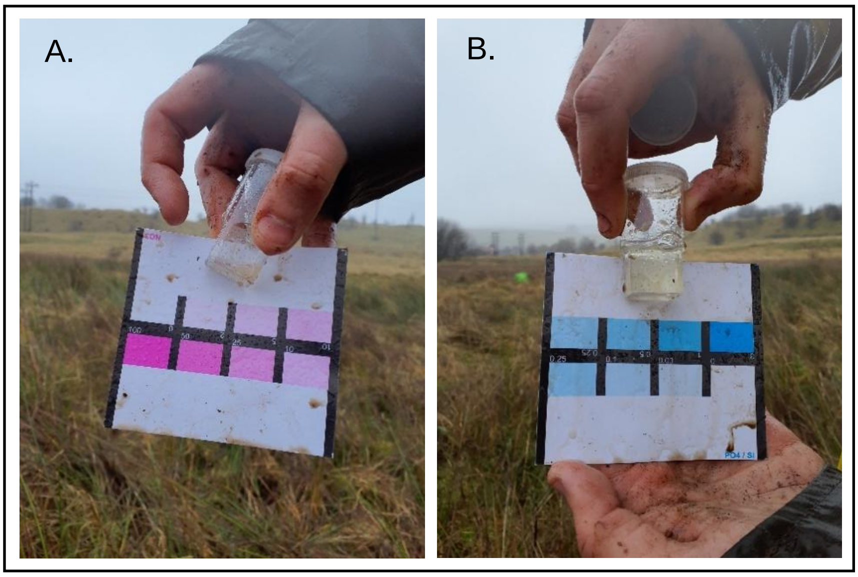

Figure 2.10: A. Nitrate test showing approx. 0-2ppm NO_3, B. Phosphate test showing <0.03ppm PO_4.

We sampled the waterbodies at 6 places in total. For phosphate levels, all of the points sampled were between 0-0.03ppm PO_4.Therefore, we are confident that the points we sampled did not have phosphate pollution.

For most of the site, the nitrate levels appeared to be around 0ppm for nitrate and so are all at acceptable levels of low or no nitrate pollution. At the pond candidate areas in the lagg fen area, one sample came up at 0ppm, but the other two samples showed 1-2ppm. The degree of separation between ‘no pollution’ at <0.5ppm, ‘some degree’ of pollution at 0.5-1.0ppm, and high or very high levels of pollution at 1-2 or 2-10ppm were too close to be very confident of any results. Unfortunately, the test we used was not sensitive enough to distinguish between this range confidentiality. Therefore, we cannot rule out nitrate pollution following this survey. As such, we will avoid those areas for new ponds, and re-sample next year.

2.5. AQUATIC INVERTEBRATE SURVEY APRIL 2024

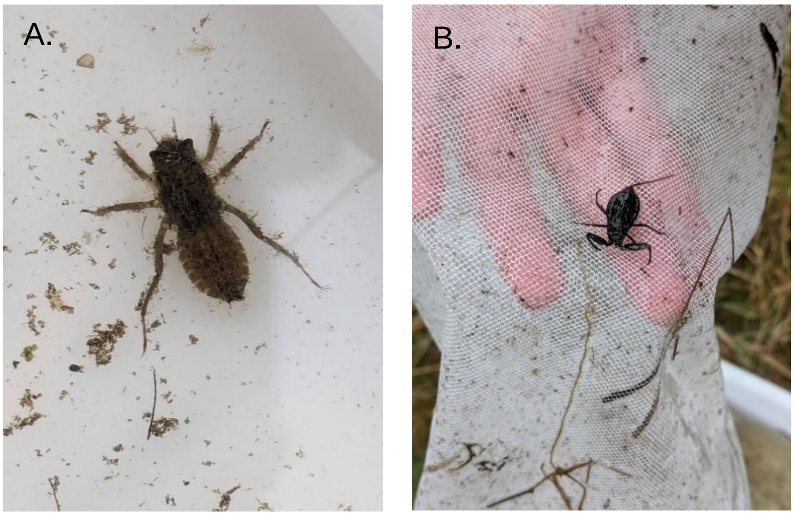

Figure 2.11 Photographs from aquatic invertebrate survey, showing A. a Four-spotted chaser nymph, and B. a Water Scorpion.

2.5.1. Survey background

The next thing to investigate was the abundance of aquatic invertebrates and the diversity of aquatic invertebrates as a baseline on the target site before any works took place.

The purpose of this survey was firstly to determine if there was enough prey for dragonfly nymphs present on site. Odonata nymphs spend most of their lives underwater, from a matter of weeks for the smaller emerald damselflies, to several years for the larger dragonflies; *L. dubia* generally take 2-3 years to develop. Dragonflies are voracious predators in their underwater phase, and they need to be able to catch and eat prey to grow and to undergo a series of moults, before the final phase where they emerge as an adult dragonfly. Therefore, this underwater ecosystem is essential for the development of the dragonfly, and it is necessary to look for an abundance and a range of aquatic prey as a food source.

The second purpose was to investigate the site for the abundance and diversity of predators; *L. dubia* are particularly susceptible to predation by fish, and they are typically not found in waterbodies containing fish in the United Kingdom. As described in the literature review in Part 1, *L. dubia* lack certain defensive features to protect against fish predation and so ponds with fish are seen as unsuitable for translocations. Other predators of *L. dubia* nymphs include larger dragonfly nymphs, tadpoles, and newt efts. So, part of the investigation was to identify any waterbodies containing fish which should be ruled out from future translocations, and to record the areas where other dragonfly predators exist.

We chose to survey 11 points across 5 habitat types across Swarth Moor: 1) the groundwater runnels in the lagg fen, as the pond candidate area, 2) grip and gully erosion features to be blocked, 3) the existing man-made ponds which contain great crested newts, 4) the natural, shallow fen pools, and 5) the shallow pools which have formed behind the cell-bunding on lowland raised bog 'peat dome' itself. The survey was carried out in April under the supervision of a great-crested newt permit holder, to mitigate and minimise disruption to the known population on site. Waterbodies were sampled with a pond-dipping net for 180 seconds at each plot, broken up proportionally to sample the number of meso-habitats e.g. for 3 meso-habitats, each area would be sampled for 60 seconds. The number and type of taxonomic groups were recorded, and the total number of invertebrate individuals was estimated.

2.5.2. Results

Encouragingly, there were no fish recorded across any of the waterbodies sampled. Therefore, fish have either not made it across to the waterbodies on this site, or else the acidic conditions are too harsh for fish to maintain populations here (For full results, see Habitat Suitability Survey and Habitat Enhancement Plan in Appendices).

Great crested newt (GCN) eggs were recorded on the man-made GCN ponds, which is a positive outcome for these mitigation ponds. These ponds were recorded previously as having a pH of 7-8, and so these are more suitable to newts and not highly suitable ponds for *L. dubia* nymphs. Frogspawn was recorded in the cell-bunding area, although not at any of the sampling locations. There clearly are large amphibian predators present on the site, although few adults were recorded, and not in all the waterbodies.

The lowest number of taxonomic groups or individuals recorded was at the drainage grip which had been installed historically to drain the site. Just 2 coleoptera (beetles) were recorded; this tells us that in its current eroding state this drainage channel is supporting almost no aquatic invertebrate biodiversity.

The natural shallow pools of the lagg fen and the fen areas recorded relatively moderate individual counts but some of the highest taxonomic diversity: around 20-40 individuals and 3-6 taxonomic groups for the lagg fen per sample, and 40-100 individuals and 5-6 taxonomic groups for the fen pools per sample. There were no Odonata larvae recorded in the lagg fen, which at the time of the survey had no ponds, but a number of beetles, bugs, and midge larvae were present in the waterlogged runnels in between the sedges and rushes. Unsurprisingly, the shallower waterbodies found in the fen did not support a wide range of aquatic invertebrate groups, but they do clearly support an ecosystem of shallow-water loving insects. In the fen pools we recorded the four-spotted chaser dragonfly nymph; the chaser nymphs have eyes which are adapted to stick up out of murky pond-debris, and ambush their prey and so they are adapted to hunting in shallow water. In conclusion, as established natural habitats they support a good diversity of taxonomic groups, but as they are shallow waterbodies there is a limit to the invertebrate abundance which they can contain.

The highest abundance of aquatic invertebrates was recorded at the man-made great-crested newt pools: up to 2000 individuals were recorded in one sample across a wide range of 6 taxonomic groups. Up to around 1000 individuals were recorded at the man-made cell-bunding of the lowland raised bog dome, although only across 3-5 taxonomic groups. This would suggest that, if installed in the right place and at the right depth, man-made pools can support a high abundance and a wide taxonomic diversity of aquatic invertebrates on this lowland raised bog.

Odonata nymphs were only recorded at two locations: at the man-made great-crested newt ponds, and in the natural pools of the fen. The great-crested newt ponds yielded a variety of Odonata nymphs: these were hawkers (common hawker or migrant hawker or southern hawker), darters (Common darter or black darter), and damselflies (common blue, azure, or emerald). While this survey did not allow enough time to get each nymph down to species, this does demonstrate the variety of dragonflies and damselflies which breed in these man-made ponds. In addition, the shallower fen pools yielded a four-spotted chaser nymph. The hawker and chaser nymphs would be predators of any *L. dubia* nymphs, which are only slightly larger than the tiny black darters. While we can't, and arguably shouldn't, try to eliminate all predators of any chosen species, this highlights a solution where ponds should be designed to a variety of depths and sizes, so that a variety of habitats is created and provides opportunities for *L. dubia* to hide from larger natural predators. (For raw data, see Appendices).

2.6. DISCUSSION OF SUITABILITY FOR WFD BEFORE PONDS CREATED

The surveys completed in 2023 and 2024 collected the data we needed to determine the suitability of Swarth Moor for white-faced darter.

We have found peat on the peat dome and in the fen to suitable depths (>80cm). We have identified that most of the peat dome was less suitable in terms of vegetation structure as it lacks the shrub shelter, but the fen and lagg fen areas were in close proximity to both tree roosts and shrub shelter.

The abiotic metrics showed that the existing waterbodies on the site are low in ionic compounds and phosphate levels, but at this stage our tests are not sophisticated enough to rule out nitrate pollution. Testing the pH revealed that the peat dome is very acidic, but most of the lagg fen is too neutral/basic for white-faced darters, leaving one area of the lagg fen which is acidic enough with a pH ≤ 6.0.

The aquatic invertebrate survey revealed that there are no fish on Swarth Moor, which are significant predators of white-faced darter. There are however a range of aquatic invertebrates, especially across the deeper waterbodies including the man-made newt ponds. The erosion channels of the grips and gullies supported very slow levels of aquatic prey.

The area these habitat suitability tests highlighted for further investigation is the acidic and peaty lagg fen. This area has no existing deep waterbodies, but it does have the right vegetation structure, aquatic invertebrate biodiversity, pH and other abiotic factors. Crucially, it has a peat depth of around 80-90cm which means it could be targeted for construction of new ponds which should provide the habitat requirements for white-faced darter.

These results allow us to assess Swarth Moor at this stage as having a potential habitat suitability for white-faced darter: it has all the essential factors as described above, and none of the deal-breakers (e.g. fish present, shallow peat etc); what it lacks currently is the waterbodies. In Part 4 we will describe how we designed ponds which would meet the requirements of the white-faced darter, and in Part 6 we will develop a quantitative score to objectively compare the habitat suitability of Swarth Moor before and after ponds are installed.

First, however, in Part 3 we describe the results of the baseline dragonfly survey for Swarth Moor and other peatlands under restoration in Yorkshire, and in nearby counties which have white-faced darter populations which could be considered for white-faced darter reintroductions.

PART 3: DRAGONFLY SURVEY SEASON RESULTS 2024

3.1. PEATLAND ODONATA IN YORKSHIRE

Swarth Moor, a nationally significant lowland raised bog with several SSSI designations and multiple pools and ponds and fen areas, had never been systemically surveyed for dragonflies before for a whole season that we know of. In fact, this special site had only 8 dragonfly records on iRecord before the project started in 2023.

Furthermore, the NBN Atlas Odonata data shows a data gap in the uplands and peatlands of Yorkshire and has considerably fewer records than the urban centres of Yorkshire and further south.

As such, we decided to set up a dragonfly transect for Swarth Moor and to survey it for the seasons in 2023 and 2024. We also surveyed a number of other peatland sites in Yorkshire which are under restoration by Yorkshire Peat Partnership to restore the bog; these were Fleet Moss in the Yorkshire Dales, and Bransdale and Rosedale Common in the North York Moors (see Figure 3.1).

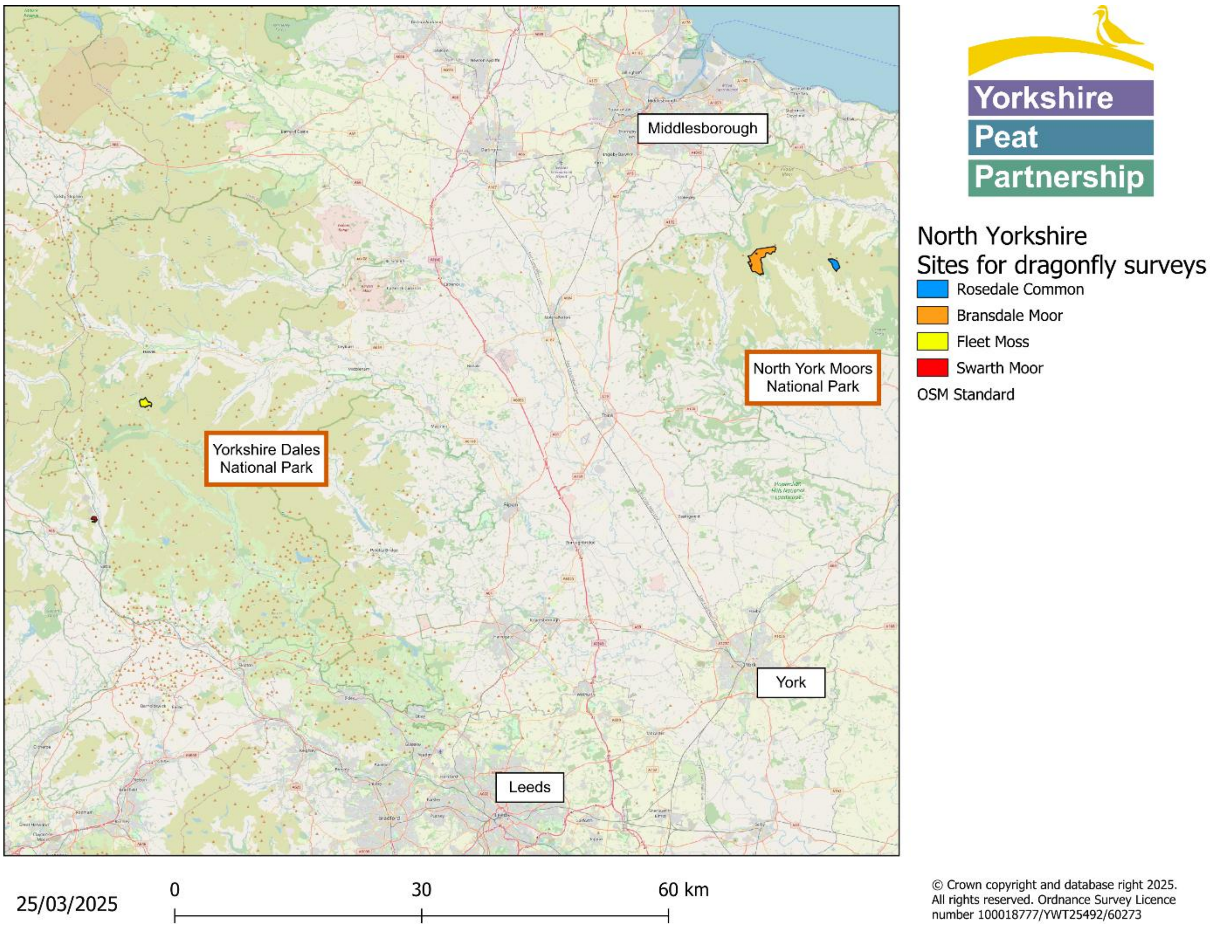

Figure 3.1 North Yorkshire sites for dragonfly surveys

3.1.1. Swarth Moor

3.1.1.1. 2023 Sept results

The funding for the Dragons in the Dales project started in August 2024, and so we surveyed Swarth Moor just twice in September.

From these surveys we recorded 8 Odonata species; these were: Black Darter (*Sympetrum danae*), Blue-tailed Damselfly (*Ischnura elegans*), Common Blue Damselfly (*Enallagma cyathigerum*), Common Darter (*Sympetrum striolatum*), Common Hawker (*Aeshna juncea*), Emerald Damselfly (*Lestes sponsa*), Emperor Dragonfly (*Anax imperator*), and Migrant Hawker (*Aeshna mixta*). (For raw data, see Appendices).

3.1.1.2. 2024 May-Sept results

	Damselflies	**Dragonflies**
1	Azure Damselfly (*Coenagrion puella*)	Black Darter (*Sympetrum danae*)
2	Blue-tailed damselfly (*Ischnura elegans*)	Black-tailed Skimmer (*Orthetrum cancellatum*)
3	Common blue damselfly (*Enallagma cyathigerum*)	Broad-bodied Chaser (*Libellula depressa*)
4	Emerald damselfly (*Lestes sponsa*)	Common Darter (*Sympetrum striolatum*)
5	Large Red damselfly (*Pyrrhosoma nymphula*)	Common Hawker (*Aeshna juncea*)
6		Emperor Dragonfly (*Anax imperator*)
7		Four-spotted Chaser (*Libellula quadrimaculata*)
8		Migrant Hawker (*Aeshna mixta*)*
9		Southern Hawker (*Aeshna cyanea*)

Table 3.1: Dragonfly and Damselfly species of Swarth Moor, recorded in 2023 and 2024.
** N.B. The migrant hawker was only recorded in 2023.*

A total of 12 dragonfly surveys were carried out between 9th May and 12th September 2025, all with the support of local surveyor volunteers. This identified the presence of 5 damselfly species and 8 dragonfly species. The most dragonflies were counted on 8th July during 'Dragonfly Week' where we recorded 270 individual dragonflies and damselflies. (For raw data, see Appendices).

Of the 57 Odonata species which exist in the UK, 14 have now been recorded on Swarth Moor, shown in Table 3.1. The golden-ringed dragonfly (*Cordulegaster boltonii*) has been seen at the quarry just north of Swarth Moor but is not included here as this sighting has not been verified.

As a result of the dragonfly surveys, YPP increased the number of dragonfly records for Swarth Moor on iRecord 27-fold!

The weather during the dragonfly survey season from May to mid-September in 2025 was very wet; this led to many surveys being postponed or cancelled. The survey guidance from the British Dragonfly Society recommends surveying in sunny conditions (<60% cloud coverage), low wind speeds (< Beaufort scale 4), with a shade temperature of less than 17°C, and no rain. However, to make the most of the wet season, surveys were carried out in sub-optimal conditions. The survey conditions ranged from 0-25% to 75-100% cloud coverage (mode cloud coverage 75-100%), wind ranged from Beaufort scale force 1 to 5 (average & mode Beaufort scale force of 2), and the temperature ranged from 13°C to 24°C (average temperature 16°C, mode temperature 14°C). We also carried out one survey in constant light rain when the forecast had been fine weather, although unsurprisingly no records were made on this day.

The weather conditions appeared to affect the dragonfly species observed (see Figure 3.2). In Figure 3.2a 'Average Cloud Cover Per Species', there seemed to be three distinct bands of species with a narrow standard error (SE) around the average cloud coverage, and so we can be more confident about the results shown: the species which were recorded around an average of 50-75% cloud coverage – large red damselfly, blue-tailed damselfly, common blue damselfly, four-spotted chaser, and azure damselfly; species recorded at or just below 25-50% cloud coverage – the black darter, common hawker, and emerald damselfly; and finally the species recorded at 0-25% cloud coverage was the common darter. This might suggest from our results that the first band was most tolerant of cloudy conditions, whereas the final band with common darter did require the sunniest conditions to be observed on the surveys. The standard error bars on the remaining species (black-tailed skimmer, broad-bodied chaser, southern hawker, and emperor dragonfly) are too wide to have much confidence in the average cloud coverage of these species; this is most likely as a result of smaller sample sizes as these species only had a small number of individuals recorded.

Figure 3.2b 'Average Beaufort Scale Per Species' shows us that, although we surveyed at up to a wind force of 5 (fresh breeze, 19-24mph), we can see that none of the species was recorded on average at these higher wind forces. Most of the species were recorded around wind force 2 (slight breeze, 4-7mph), including the lighter bodied species such as black darter and most of the more delicate damselflies including the large red damselfly, blue-tailed damselfly, common blue damselfly and the azure damselfly. Interestingly, a few species stand out as on average being recorded at the windier Beaufort scale 3 (gentle breeze, 8-12mph) which were the common darter and the emerald damselfly. The Emperor dragonfly also was recorded on average at Beaufort scale 3, which is the largest-bodied dragonfly on the site, although with a large standard error. It is possible some certain dragonfly species such as the common darter, emerald damselfly, and Emperor dragonfly are more tolerant of slightly windier conditions, perhaps adapted to the exposed habitats where they can be found.

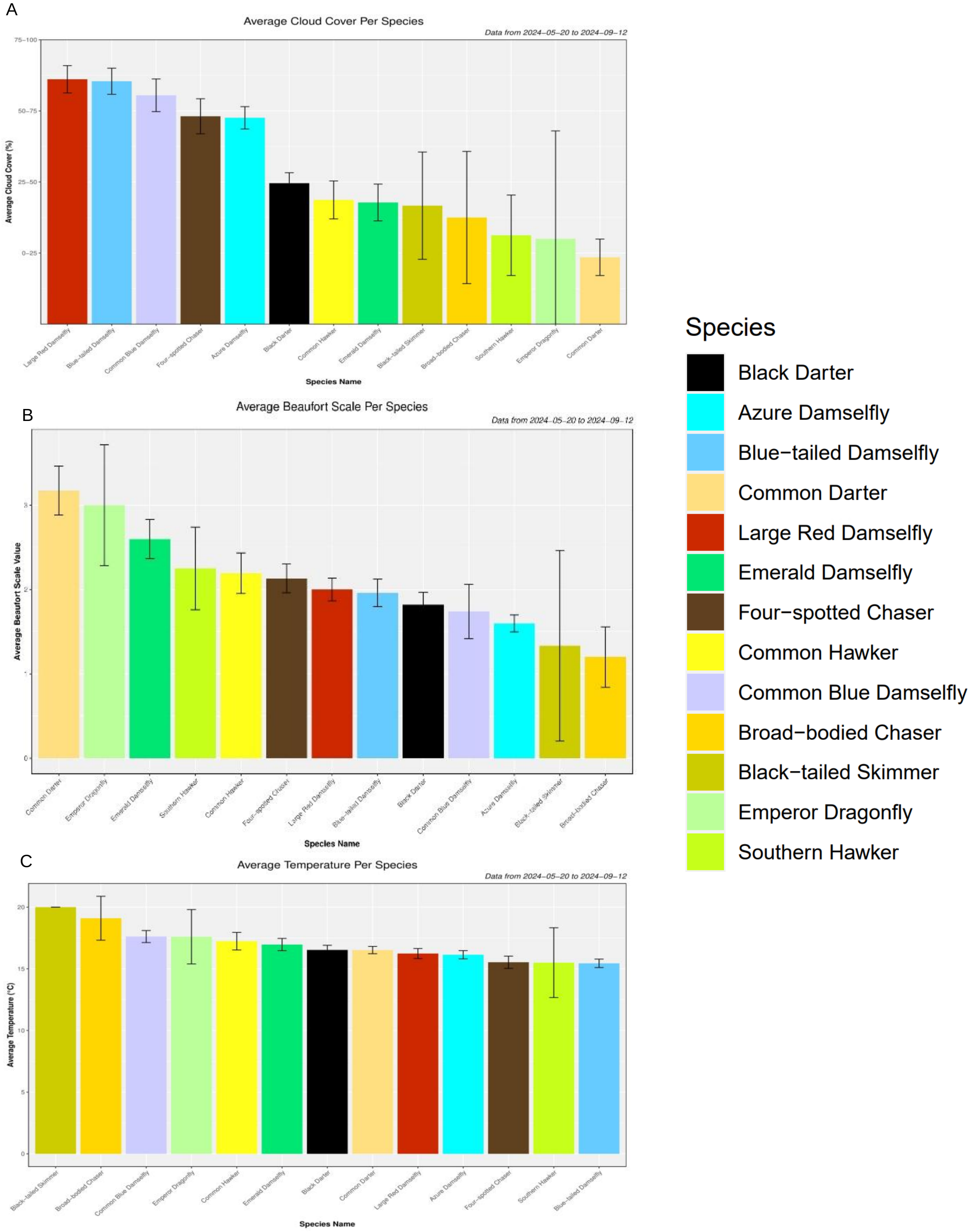

Figure 3.2. Bar charts showing weather conditions and dragonfly species. A. Average cloud cover (%) per species, B. Average Beaufort scale per species, C. Average temperature (°C) per species (SE = standard error from the mean value).

In Figure 3.2c ‘Average Temperature Per Species’ we can see that most species were recorded at similarly warmer temperatures, averaging about 16°C. From the results of the survey weather conditions it seems that some species are able to tolerate slightly windier conditions and some are able to tolerate full cloud, but all species consistently preferred warm conditions above 15°C. Although dragonflies were recorded at the lowest temperature surveyed (13°C) warm temperatures are required for dragonflies to warm themselves up and be active. So, an overcast day with a fresh breeze would still record dragonflies so long as it was warm enough. Dragonflies do exist in plenty of windy and cloudy habitats, such as the exposed moorlands and peatlands of the Yorkshire Dales and the North York Moors, as we will see. So, they must be able to tolerate these conditions, so long as they get the temperatures needed to warm up.

The surveys recorded not just species numbers, but also the life stage at which the individual was observed at (Figure 3.3). The majority of the records were adults, seen flying or perched along the transect. Copulating pairs were recorded for black darter, common darters, common hawkers and in all of the damselflies except common blue damselfly. We also recorded exuviae and some emerging individuals, which definitively indicates successful breeding from a waterbody, from the following species: large red damselfly, four-spotted chaser, common hawker, emerald damselflies, and black darter. The most numerous species for damselflies was the azure damselfly and for the dragonflies was the black darter.

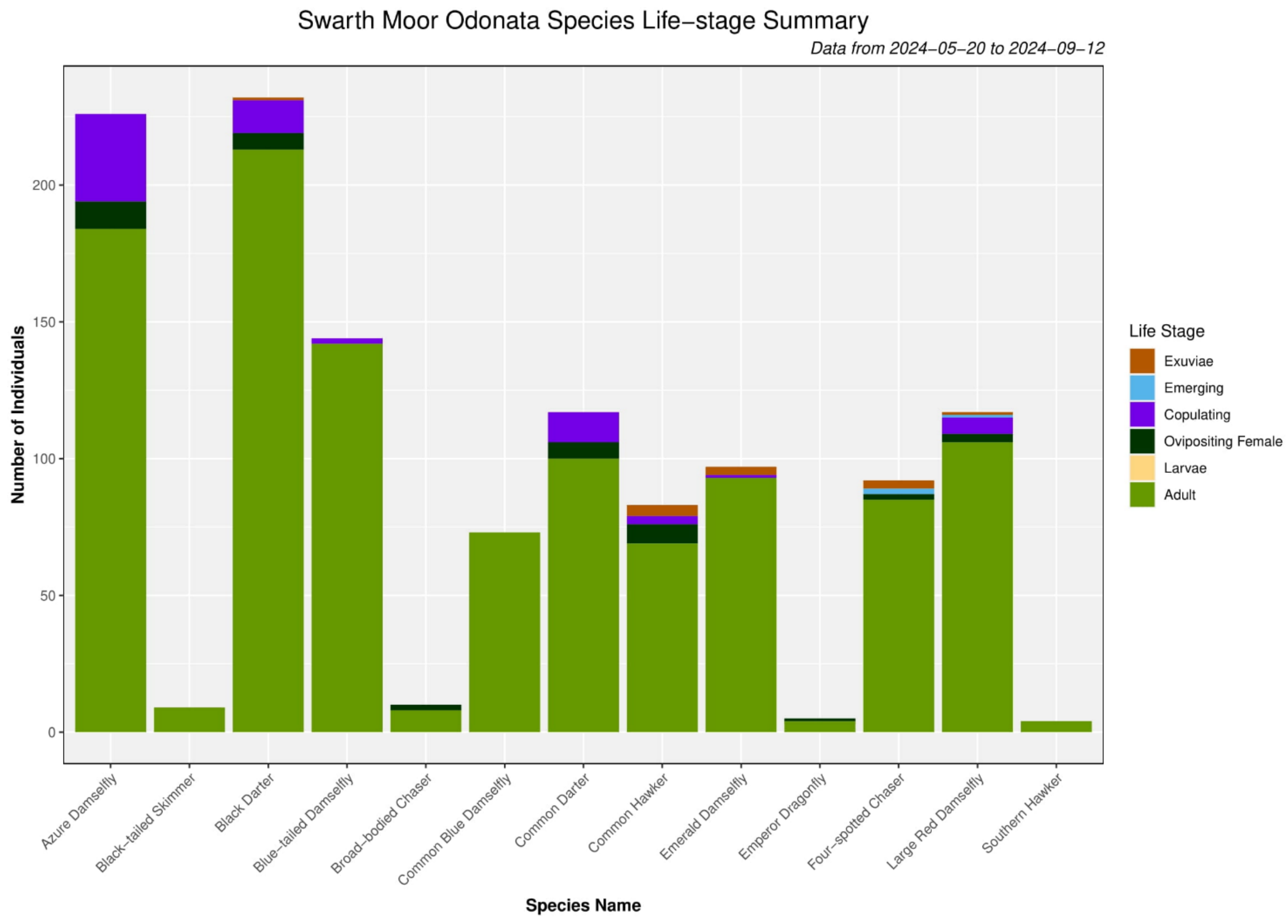

Figure 3.3: Swarth Moor Odonata Species Lifestage Summary: bar chart showing the number of individuals recorded per species at each lifestage, from exuviae, emergents, copulating pairs, ovipositing females, larvae i.e. nymphs, and adults.

Different species emerge as adults at different times throughout the summer (see Figure 3.4). Many of the damselflies emerged first, the large red damselfly being the first species we recorded during the rainy and chilly May. The black-tailed skimmer and broad-bodied chaser were only recorded in low numbers in the middle of summer in the best weather. The species last seen flying at the end of the survey season in September were the black darter, common hawker, emerald damselfly, and southern hawker.

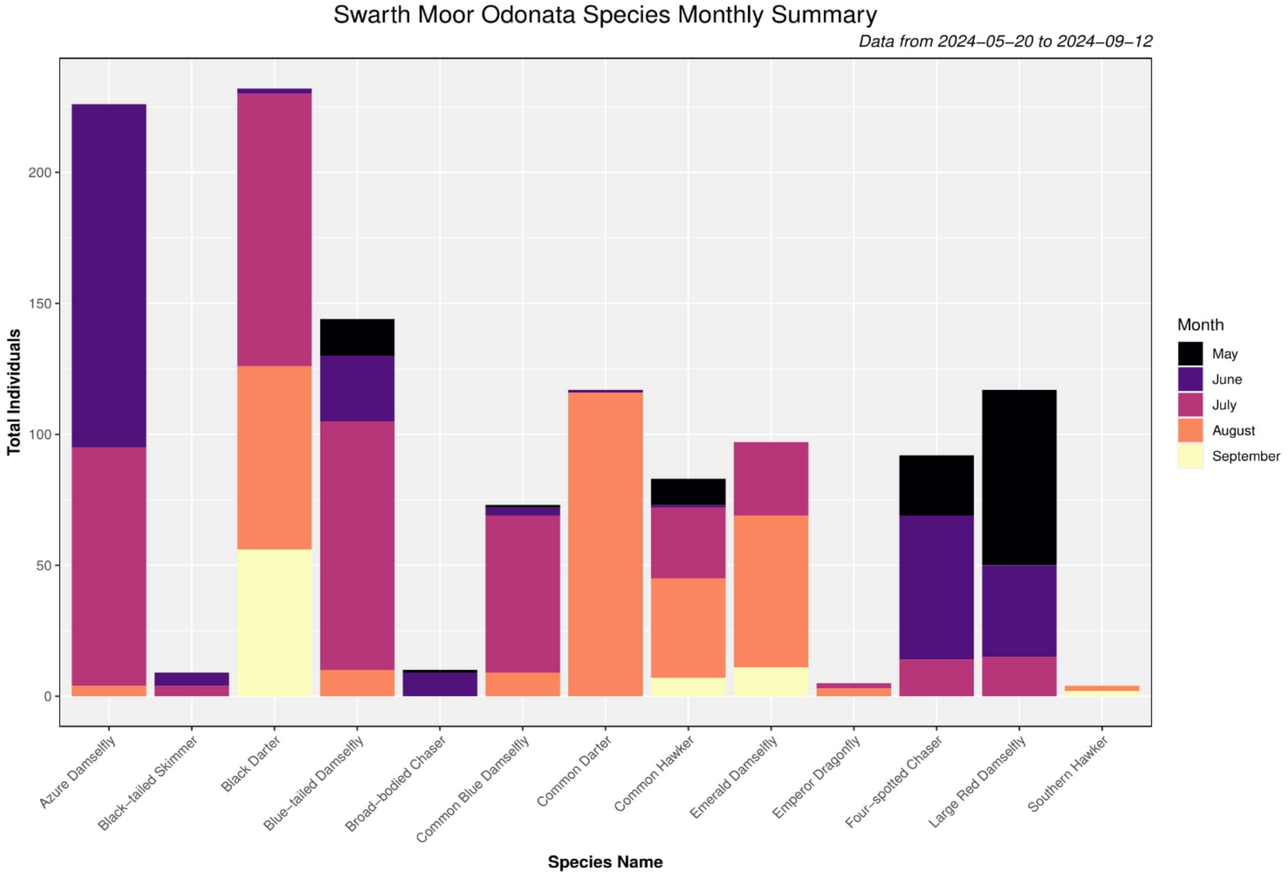

Figure 3.4: Swarth Moor Odonata Species Monthly Summary: bar chart showing the number of individuals recorded per species per month for May (black), June (purple), July (pink), August (orange), September (cream).

3.1.1.3. Habitat preferences

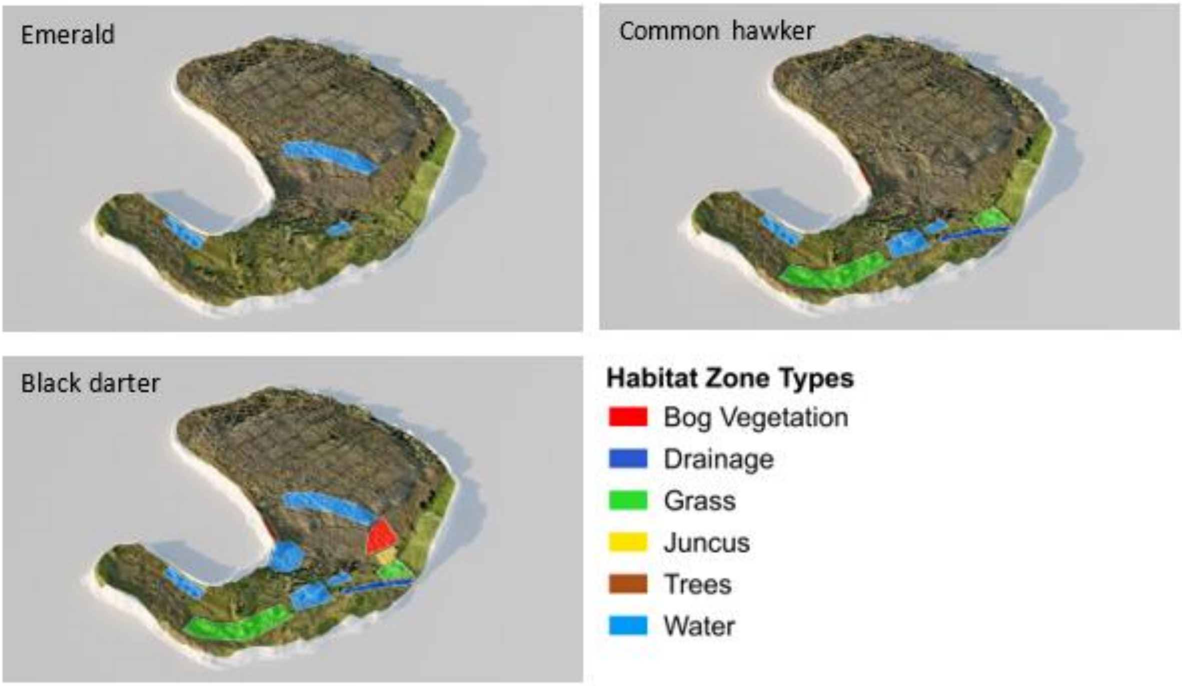

Figure 3.5: 3D height maps of Swarth Moor. Habitat zones show the broad habitat and features of the areas through which the dragonfly transect walked, and where the peatbog dragonflies were recorded: emerald damselfly, common hawker, and black darter.

The survey transect on Swarth Moor was broken up into 4 parts: 3 were 'point counts' taken at different waterbodies or features, and the last was the catch-all transect, T1. At each of the points surveys, we stopped for a standard 20-30minutes.

The transect crosses through a range of habitats and vegetation structures which are present across Swarth Moor: starting through the acidic flush soft rushes *Juncus effusus*, and passing healthier bog vegetation before heading up and then along the shallow pools on the edge of the cell-bunding of the peat dome. Off the peat dome, the transect goes to the boardwalk platform which is the first point count (P1), which faces a region of the peat dome which is still dry and covered in purple-moor grasses *Molinia caerulea*. Off the boardwalk you walk on the boundary track with the quarry amongst birch and willow trees. Just past these trees are the shallow pools of the central fen. The transect then stops at the next point count (P2), which is the first of the man-made 'great crested newt' ponds. The transect then weaves past the other two newt ponds, before crossing the *Molinia* tussocks which dominate the lagg fen and is planned for coir bunding to restore the hydrology here. The next point count is P3, which was taken approximately in the location planned for one of the dragonfly ponds, to be created later in autumn of 2024; this is on an area of lagg fen bordered and sheltered by scrubby willow trees. Past the pond candidate area, is the other side of the shallow fen pools in an area of bulrushes. The final stretch of the transect was along the drainage channel known as ‘Black Sike’, which is be blocked in autumn of 2024.

As shown in Figure 3.5, the broad habitat zones along T1 were favoured to different degrees by the different dragonfly species. For example, the emerald damselfly was mostly recorded around the shallow cell-bunding pools, the bulrush fen pools and the deeper great crested newt ponds. The common hawker was found across more of the habitat zones on Swarth Moor, although it was not seen as frequently on the boggier areas of the peat dome itself. The black darter, on the other hand, seemed to be comfortable in all of the habitat zones across the Swarth Moor transect.

The four-spotted chasers would appear from the soft rushes and were seen laying in all the pools seen in the survey. All the damselflies favoured the shelter of the trees and scrub on the site. The Broad-bodied chaser and black-tailed skimmers seemed to especially favour the shallower pools of the central fen, exhibiting territorial behaviour towards each other. A female emperor was first seen ovipositing in the newt ponds at P2 and seemed to favour these deeper ponds, but they were also spotted by the scrubby trees near P3.

In Figure 3.6, we have broken down the number of species observed, and the number of individuals observed per point count / transect. This confirms that the boardwalk P1 facing the peat dome recorded both the lowest range of dragonfly species and the lowest total number of individuals, compared to the other points and the transect. Although some records were made for the transect T1 along the wetter pools along the cell-bunding, there were rarely any records made at the boardwalk. In future years, with the action of the cell-bunding made in 2020 allowing the water table to rise across the whole peat dome, perhaps we will see more dragonflies using the shallow pools of the bog itself. For the moment, however, the restoration is still taking time, and the outer cells are too dry year-round for dragonflies to lay eggs or hold territory over.

The great crested newt point count (P2) recorded almost all of the species found on the whole transect T1 combined. Perhaps these man-made ponds provide such a range of aquatic niches that most dragonflies benefited from these habitats. These ponds were installed as part of the cell-bunding restoration work carried out by the NNR site managers at Natural England in 2020, so it is a credit to them that these ponds clearly seem to be supporting a wide range and abundance of dragonflies only 4 years later. This also gives credence to the idea that man-made wildlife ponds can become rapidly beneficial to dragonflies, including nationally declining ones like the black darter, common hawker, and emerald damselfly (The State of Dragonflies Report, BDS, 2021).

The data from P3, in the area planned for dragonfly ponds, will hopefully act as a ‘before’ data sample, to be compared with records after the ponds have been constructed over time. As of 2024, the lagg fen is dominated with *Molinia*, and although it does have a range of waterlogged runnels making up the fen, it doesn’t have any deeper water in this area for dragonflies to lay in. The lagg fen was recorded as supporting 10 dragonfly species, just behind P2, but we recorded about half as many individual dragonflies in this area. It will be interesting to return to P3 in the coming years to see what effect the peat-bunding and pond-construction will have on the dragonfly numbers in this area.

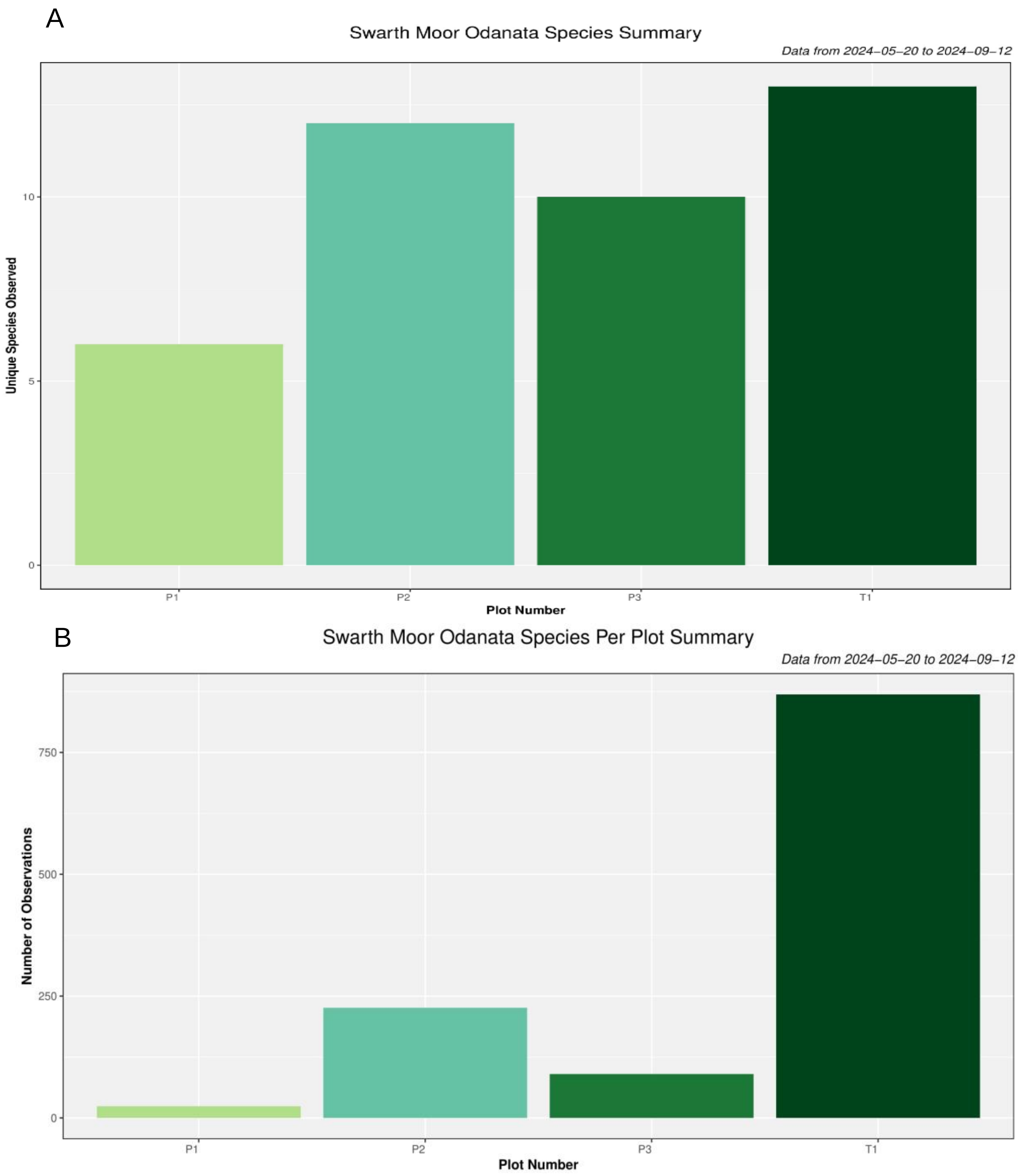

Figure 3.6. Bar charts of dragonfly records per plot, at the point plots P1 P2 P3 and across the transect T1. A. Total number of Odonata species recorded per plot, B. Total number of Odonata individuals recorded per plot.

3.1.2. Fleet Moss 2022 vs 2024 results

Fleet Moss is situated in the parish of Bainbridge in the Yorkshire Dales National Park. It covers an area of approximately 643 hectares.

Fleet Moss is one of the most degraded upland peatlands in Yorkshire. The bog is criss-crossed with drainage ditches (grips) and erosion channels (gullies) that flush water and sediment into the Wharfe and Ure river catchments.

YPP has delivered extensive restoration on Fleet Moss, starting in 2014/2015, then in 2018, finishing the most recent round of works in 2024, with funding from Defra, the EU Life Programme 'Pennine PeatLIFE', Yorkshire Water, the Environment Agency and the Garfield Weston Foundation. The work has involved the installation of 10's of thousands of dams and sediment traps to hold water and peat on the bog, allowing vegetation to re-establish. YPP has also planted over 200,000 cotton-grass, dwarf-shrub and sphagnum moss plugs on over 8 hectares of bare peat. On the most extensive 'peat pans' of erosion where machinery cannot access, the exposed peat has been re-vegetated and broken up using coconut-coir logs, which allows sensitive bog vegetation to re-establish (see Figure 3.7).

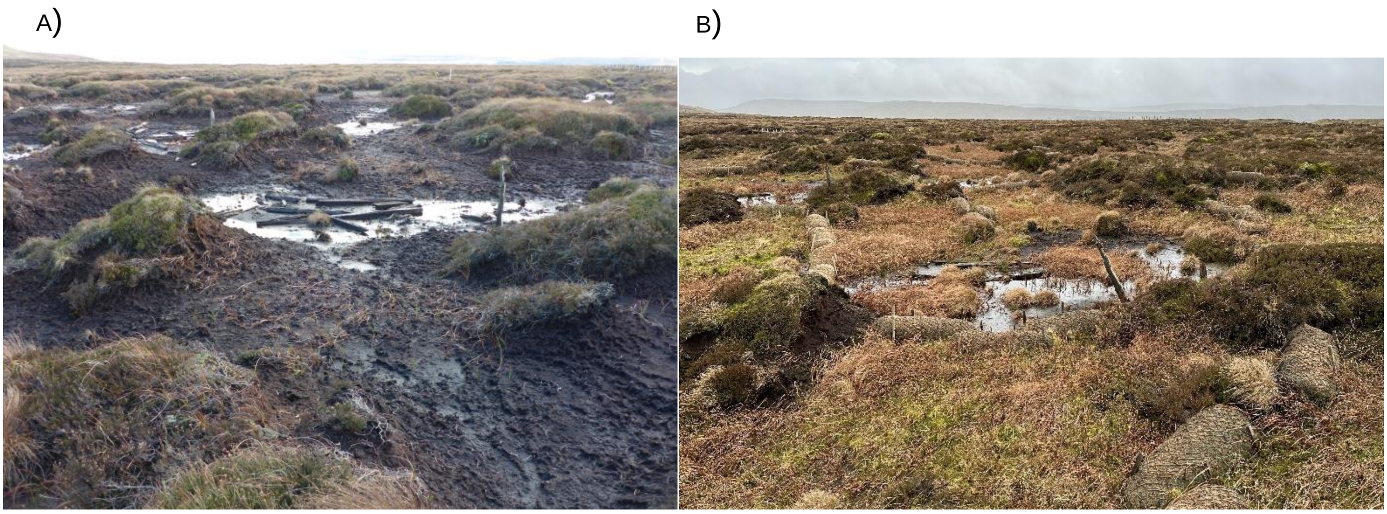

Figure 3.7: Fleet Moss 'Before and After' photograph taken of the same spot 6 years apart. A) Before phase 2 restoration in 2018, and B) After several years of restoration works, taken in 2024. Photo credit: Jenny Sharman, YPP.

Healthy upland peatlands are not just beneficial in terms of carbon storage, water quality and reducing flood peak flows into the river catchments downstream, they are also important places for biodiversity. It follows that restoration of damaged peatlands should result in an increase of biodiversity. We have anecdotally seen an increase of dragonflies of these upland sites making use of the pools of water which form behind the sediment-traps and bunds. It is hard to imagine any dragonflies or damselflies breeding on the bare 'moonscape' of Fleet

Moss pre-2018 (see Figure 3.7a); however, we have no empirical data to evidence this. Up to this point YPP had not been involved in measuring the impact of peat restoration on outcomes such as insect biodiversity. This is something we want to start monitoring, and the Dragons in the Dales project provided the opportunity to begin this important data collection.

In 2022 and 2024, June and Keith Gittens (VC62 and VC65 Dragonfly County recorder) joined YPP to survey for dragonflies and damselflies on Fleet Moss.

The 11th August 2022 was an uncharacteristically hot and sunny day for Fleet Moss, in a summer which experienced two record-breaking heat waves, and the hot weather was reflected in the dragonfly activity we recorded (Table 3.2). We recorded 3 damselfly species, and 5 dragonfly species including breeding behaviour in the common hawker and four-spotted chaser.

	Damselflies	**Dragonflies**
1	Common Blue Damselfly (*Enallagma cyathigerum*) – 1Ad	Black Darter (*Sympetrum danae*) – 10-25 Ad, 1 Ovi
2	Emerald damselfly (*Lestes sponsa*) – 12-35 Ad	Emperor Dragonfly (*Anax imperator*) – 1 Ad
3	Large red damselfly (*Pyrrhosoma nymphula*) – 2 Ad	Common Darter (*Sympetrum striolatum*) – 4-10 Ad
4		Common Hawker (*Aeshna juncea*) – 10-25 Ad, 1 Cop
5		Four-spotted Chaser (*Libellula quadrimaculata*) – 1 Ad

Table 3.2: Dragonfly and Damselfly species on Fleet Moss, recorded on 11th August 2022.

The 24th June 2024 was a fairly hot but cloudier day on Fleet Moss, in an unusually cool and frequently wet summer. We recorded 4 damselflies and 5 dragonfly species, adding the azure and blue-tailed damselflies and the broad-bodied chaser to the species list from 2022, and not recording the common blue and the emperor dragonfly this time (Table 3.3). We recorded more breeding behaviour in June 2024 than in August 2022, observing this in the azure and large red damselflies, and witnessing two common hawkers emerge from their exuviae and one taking its maiden flight (Figure 3.8). (For raw data, see Appendices).

	Damselflies	Dragonflies
1	Azure Damselfly (*Coenagrion puella*) - 5 Ad, 1 Cop	Black Darter (*Sympetrum danae*) – 1 Ad
2	Blue-tailed damselfly (*Ischnura elegans*) – 2 Ad	Broad-bodied Chaser (*Libellula depressa*) – 1Ad
3	Emerald damselfly (*Lestes sponsa*) – 1 Ad	Common Darter (*Sympetrum striolatum*) – 1 Ad
4	Large red damselfly (*Pyrrhosoma nymphula*) – 45 Ad, 20 Cop	Common Hawker (*Aeshna juncea*) – 2 Ex, 2 Em
5		Four-spotted Chaser (*Libellula quadrimaculata*) – 1 Ad

Table 3.3: Dragonfly and Damselfly species on Fleet Moss, recorded on 24th June 2024.

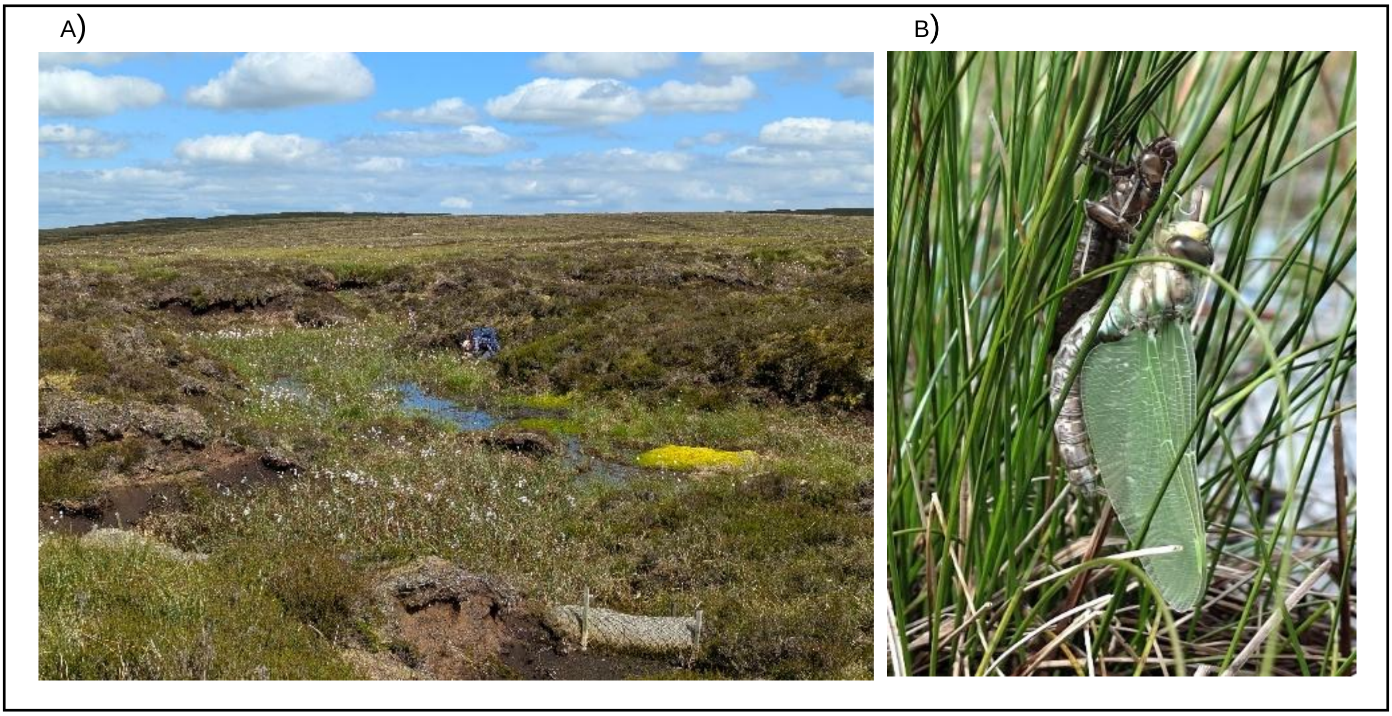

Figure 3.8: Fleet Moss dragonfly survey June 2024. A) Showing one of the bog pools which has formed following extensive restoration, and a surveyor marking out the location of B) an emerging common hawker dragonfly and exuvia. Photo credits: Liberty Firby-Fisk, Jessica McMaster, YPP.

3.1.3. Bransdale Moor & Rosedale Common 2024 results

Bransdale Moor and Rosedale Common are both blanket bogs within large grouse estates in the North York Moors National Park. These sites are managed by a programme of rotational burning to create a patchwork of all the growth stages of heather growth for the red grouse.

Bransdale Moor covers a large area (~5,940 hectares) of upland blanket bog within North York Moors National Park. YPP has been involved in restoration on 685 ha between 2018 and 2024, funded by Countryside Stewardship and Nature for Climate Programme, which delivered over 5000 bunds and sediment traps and over 2 hectares of bare peat revegetation with cottongrass and sphagnum plugs (see Figure 3.9).

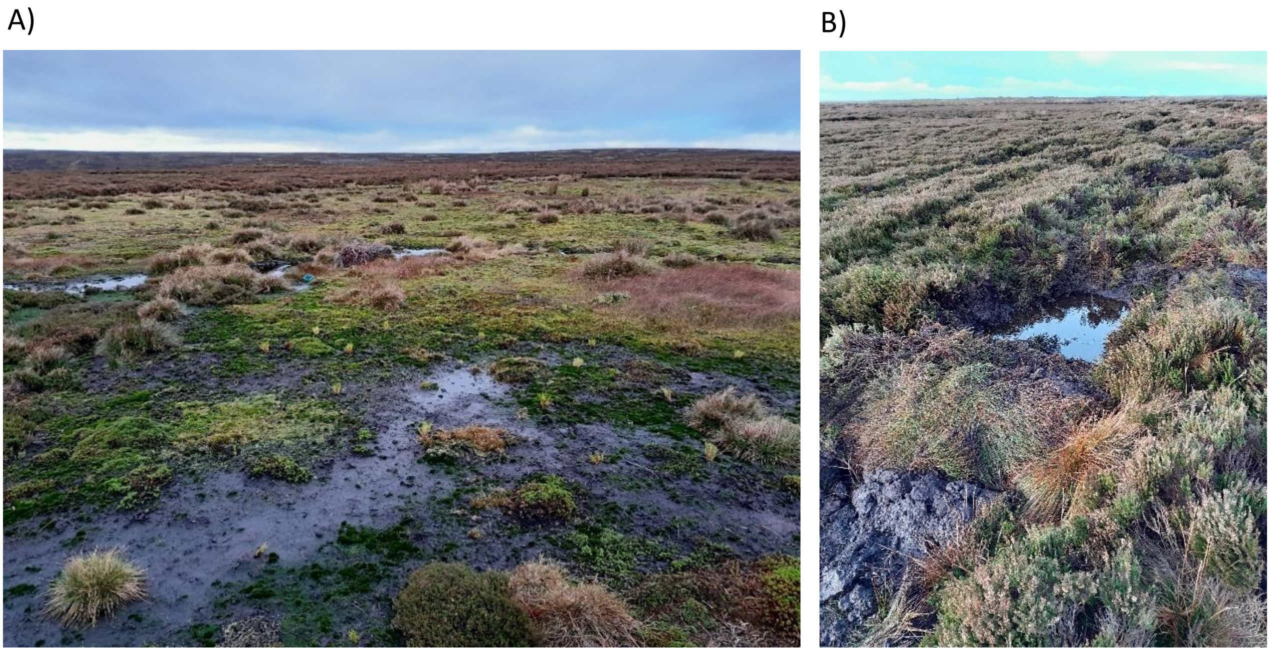

Figure 3.9 – Photographs of Bransdale Moor survey area in 2024 post-restoration, showing A) Species-poor M19 Blanket Bog with cottongrass planting, and heather bale bunds forming pools in the background, and B) Peat bunds forming pools with the aim of raising the water table. Photo credit – Kane Szuman, YPP.

	Damselflies	**Dragonflies**
1		Black Darter (*Sympetrum danae*) – 8 Ad, 1 Ovi
2		Common Hawker (*Aeshna juncea*) – 9 Ad, 1 Ovi

Table 3.4: Dragonfly and Damselfly species on Bransdale, recorded on 29th August 2024. Cloud cover was 25-50%, wind speed was factor 5, the temperature was 15°C.

YPP, along with Keith and June Gittens, visited Bransdale Moor and Rosedale Common on the 29th August 2024, on a warm clear day with a fresh breeze. The Bransdale survey focused on an area with peat dams in the 1-2m drainage channel ‘grips’, which have now formed small pools (Figure 3.9b). Only two dragonfly species were recorded on Bransdale on this day – the black darter and common hawker, and zero damselflies were recorded (Table 3.4). Clearly from the data on Fleet Moss, dragonflies and damselflies can be recorded on exposed upland degraded blanket bogs under restoration; however, Bransdale barely recorded 20 individuals on this survey. (For raw data, see Appendices).

Rosedale Common is situated about 9km to the east of Bransdale Moor. It is also part of a larger grouse estate, however YPP targeted 50 hectares for restoration in 2023/24. This work included over 400 sediment traps and bunds and 0.25 hectares of bare peat revegetation. The work was particularly focused on a 0.45km erosion channel which had formed partly as a result of foot-traffic (Figure 3.10a); the peat-and-heather-bale dams which were installed rapidly filled with water, creating 2-3m wide and up to 1.8m deep bog pools (Figure 3.10b). In the same summer of 2023, upland birds (including red grouse chicks) and dragonflies (e.g. large red damselflies as in Figure 3.10c) were immediately observed being attracted to the newly formed waterbodies.

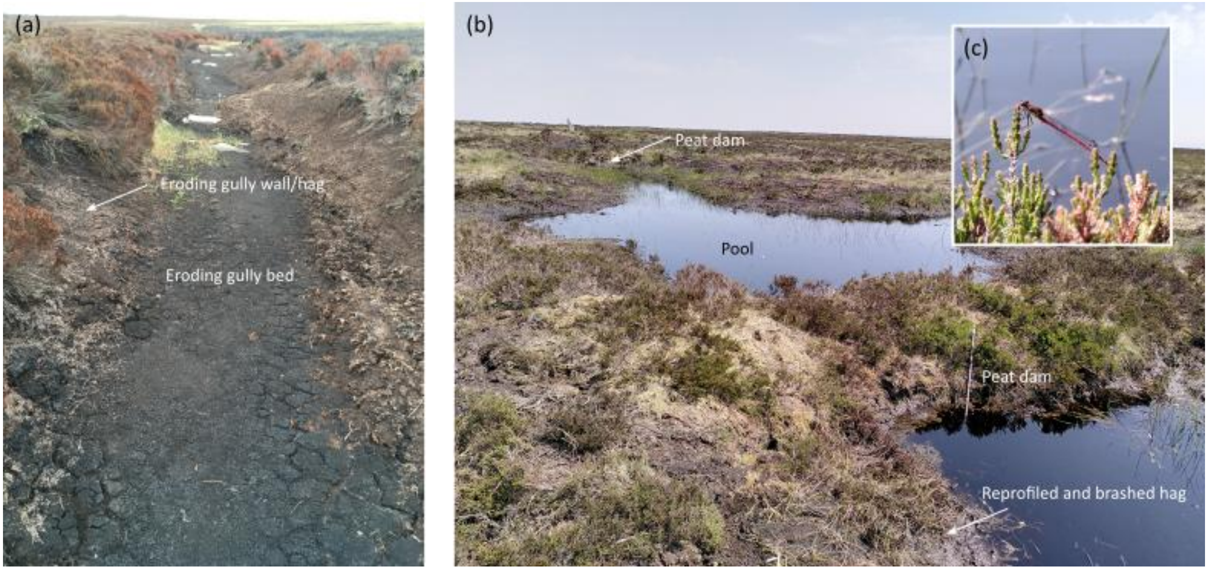

Figure 3.10 – Photographs of Rosedale Common dragonfly survey area, showing A) Large gully pre-restoration in 2020, and B) the same gully in 2023 post-restoration with peat dams in place, slowing the flow of water and creating permanent waterbodies and consequently habitat for C) dragonflies and damselflies. Photo credit - Rosie Snowden 2020 and Jessica McMaster 2023, YPP.

On the afternoon of the 29th August 2024, YPP surveyed this area of Rosedale Common with Keith and June Gittens. It was just as warm and breezy as on Bransdale, but with a higher cloud coverage. However, despite the more overcast conditions, Rosedale Common recorded significantly more Odonata than on Bransdale: 1 damselfly species, and 4 dragonfly species, with breeding behaviour recorded in the black darter and common hawker (Table

3.5). It appears that the dammed erosion channel on Rosedale Common is now thriving with dragonflies, which seems to show that restoration in both the upland blanket bogs of the Yorkshire Dales and in the North York Moors can support a range and some abundance of dragonfly species. The bog pools created on Rosedale Common seem to be more attractive to dragonflies than on Bransdale Moor, both surveyed on the same day and in very similar conditions, possibly as they resulted in deeper and wider waterbodies. They may provide a wider range of micro habitats, or perhaps because the water table is now much higher on Rosedale than on Bransdale and so the waterbodies present there are less likely to dry out than on Bransdale, which is still quite dry. This would suggest that the style of restoration has an effect on dragonflies recolonising an area.

	Damselflies	**Dragonflies**
1	Emerald damselfly (*Lestes sponsa*) – 10 Ad	Black Darter (*Sympetrum danae*) – 29 Ad, 4 Cop, 3 Ovi
2		Common Darter (*Sympetrum striolatum*) – 1 Ad
3		Common Hawker (*Aeshna juncea*) – 11 Ad, 1 Cop, 2 Ovi
4		Emperor Dragonfly (*Anax imperator*) – 1 Ad

Table 3.5: Dragonfly and Damselfly species on Rosedale Common, recorded on 29th August 2024. Cloud cover was 50-75%, wind speed was factor 5, the temperature was 15°C.

3.1.4. Discussions on peat restoration, bog condition & dragonfly biodiversity

In this section we describe the first pre-restoration full-season dragonfly survey completed on a lowland raised bog in the Yorkshire Dales. This data has created a useful baseline of Odonata records before restoration of lagg fen area and creation of new dragonfly ponds.

The surveys of Swarth Moor show that this SSSI supports a range of dragonflies, including the nationally declining emerald damselfly, common hawker, and black darter.

Different species were recorded as being more-or-less tolerant of sub-optimal weather conditions; for example, the common darter and the emerald damselfly seemed to be tolerant of the breezier conditions, and large red damselfly, blue-tailed damselfly, common blue damselfly, four-spotted chaser, and azure damselfly were all present on the cloudier surveys. On the other hand, all species preferred similarly warm temperatures, so this may be the most important factor for dragonfly activity.

One of the most encouraging results was the range and abundance of dragonflies recorded post-restoration on upland blanket bogs in both the Yorkshire Dales and North York Moors. In the right conditions, dragonflies and breeding behaviour were recorded within a matter of months of peat restoration.

The style of peat restoration interventions (e.g. depth and permanence of waterbodies created) appears to impact the diversity of dragonflies which recolonise restored blanket bogs in the North York Moors.

The results of these surveys shows that peat restoration plays an important role in restoring habitat for dragonflies and damselflies. The potential benefit for biodiversity, such as Odonata, should be considered when drawing up peat restoration plans, and future pre- and post-restoration monitoring of such biodiversity outcomes should be considered.

3.2. WHITE-FACED DARTERS IN ENGLAND AND WALES

In England and Wales, since 2023 the white-faced darter has only been recorded in these 5 counties: Wrexham in Wales, and Shropshire, Cheshire, Staffordshire, and Cumbria in England.

Of the significant populations of white-faced darter, the closest to the target site for this project (Swarth Moor, North Yorkshire) are shown in order of distance: Foulshaw Moss (37km, Cumbria), Doolittle Moss in Delamere Forest (100km, Cheshire), Scaleby Moss (103km, Cumbria), Drumburgh Moss (103km, Cumbria), Fenn's & Whixall Mosses (134km, Wrexham & Shropshire), and Chartley Moss (143km, Staffordshire).

There has been a series of successful reintroductions within and across these counties so far, and now there is increasing interest in other locations further afield. Two sites which have been involved as donors in such reintroductions in the past are: Fenn's & Whixall Mosses, sitting on the Welsh/English border, and Scaleby Moss in Cumbria. Further information about the population trends on these sites and the outcomes of past reintroduction programs is described in Part 1.3 of the literature review.

The previous and current reintroduction projects have all involved rigorous monitoring of white-faced darter populations in the donor sites, especially using exuvia counts, to track any negative impact that the translocations may have on the donor populations. These data are also crucial in tracking population trends in white-faced darter in general in England and Wales.

For us to understand how a reintroduction to our target area would proceed in future, it was therefore essential to understand how white-faced darter populations were doing at the nearest potential white-faced darter donor sites. For the purposes of this project, we discuss Fenn's & Whixall Mosses, and Foulshaw Moss and Scaleby Moss.

3.2.1. Fenn's & Whixall Mosses, Wrexham & Shropshire

Fenn's, Whixall and Bettisfield Mosses (NNR/SSSI) are one of the largest lowland raised bog peatlands in England and Wales at 966 hectares. These mosses have been a very important refuge for the white-faced darter to date, especially for Wales where this is the only stronghold for this species.

During the Delamere white-faced darter reintroduction project, the Fenn's & Whixall Mosses were the donor site used for the translocation. Consequently, they were monitoring routinely between 2013-2016, during which the exuvia counts for a standard three ponds were between 600 and 1,400 per season. The next full count was in 2019, when it was just under 600 exuvia.

The following full count of the three survey ponds was in 2023, which yield a poor result for white-faced darter exuvia, with under 300 exuviae collected; the reserve managers at Natural England for Fenn's & Whixall Mosses say it is uncertain at this stage what caused this decline in populations, although one possible reason suggested was an algal bloom which appeared on the mosses, and in particular was covering one of the three survey pools. However, by 2024 the exuvia count had risen once again to almost 1,500, the highest record yet for the site.

What this does tell us is that there is considerable variability in the white-faced darter survey results, even in these crucial refuges such as Fenn's & Whixall Mosses. The reason for the apparent fluctuations may simply be a result of sampling bias – it is only physically possible to safely access 10% of the pools on these sites for routine surveying; it could be that the populations remain constant across the site as a whole, as the dragonflies move from one pool to the next as the pools' suitability changes from year to year. The alternative reason may be more troubling, that the white-faced darter populations are very sensitive to the environment, possibly including to these algal blooms. This makes it more imperative to secure funded monitoring and for research carried out into the habitat requirements of this species.

Exuvia counts were also made separately across the English and Welsh pools for Fenn's & Whixall Mosses. On the English side, 4 survey pools were surveyed, and on the Welsh side, 5 pools were surveyed, each around 50m^2 to 200m^2 (mean 125m^2). The total 2024 exuvia count for the English pools was 1,380, and for the Welsh pools was 479.

3.2.2. Foulshaw Moss and Scaleby Moss, Cumbria

Scaleby Moss (SSSI) is a 65 hectare lowland raised bog in northern Cumbria. Historically, it has been degraded by domestic peat-cutting and is now threatened by unmanaged regeneration of pine and birch. It has been known as a one of the few English white-faced darter populations since 1946 and as such was used as the donor site for the reintroduction to Foulshaw Moss in south Cumbria (Clarke, 2014). Scaleby Moss has also been the donor source for a first-time introduction project at Drumburgh Moss on the English Solway, which completed in 2024. Drumburgh (NNR) and Foulshaw (SSSI/SAC) are both managed nature reserves of Cumbria Wildlife Trust, who have been carrying out extensive restoration work on these large and important peatlands.

Exuvia counts were carried out on the Cumbria sites in 2024. All pools are roughly equivalent in size, 40-50m^2, as they were dug to a specification to match the original population on Scaleby Moss. The results are as follows: Foulshaw Moss across 4 pools - 1,166, Drumburgh Moss across 6 pools – 681, Scaleby Moss across 6 pools - ≥ 1,869. The Scaleby Moss results are only up to 21st May when especially poor weather resulted in cancelling the remaining counts, so should be taken as only the minimum that these pools would have recorded this year. Excitingly, the Drumburgh exuvia count is the highest to date for this site, which is another very encouraging result.

3.2.3. Discussion of donor populations

The 2024 exuvia counts of the five white-faced darter sites are shown in Figure 3.11. To make the results more comparable, the exuvia counts have been taken as an average and adjusted per 100m^2 pool from the 2024 surveys.

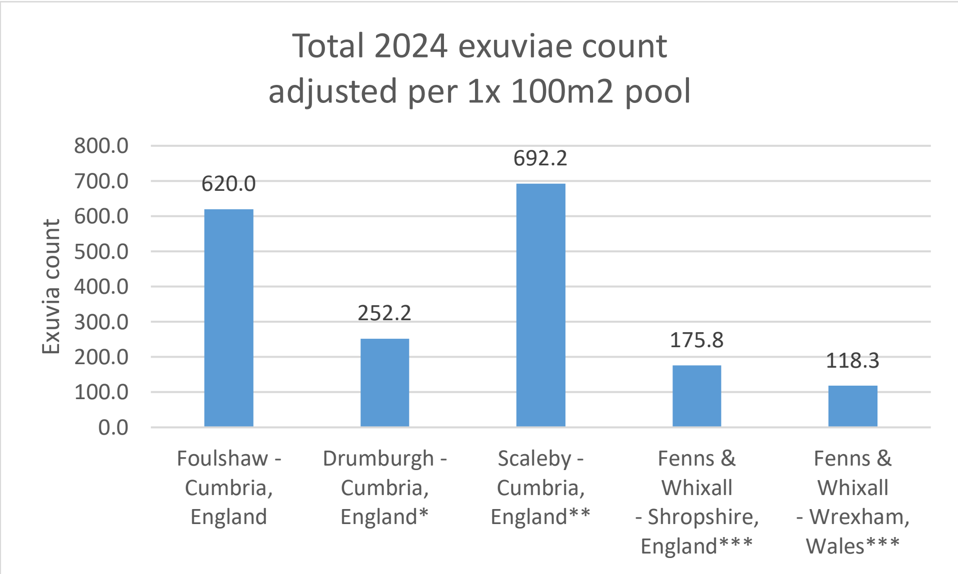

*Figure 3.11 – Total exuvia count for 2024, adjusted to count per 1x100m^2 pool, for 5 different sites across England and Wales with white-faced darter populations. *It should be noted that Drumburgh Moss's results were taken during the 2018-Present reintroduction on this site, so this population is likely still in its growth phase. **The Scaleby Moss results are only up to 21st May when especially poor weather resulted in cancelling the remaining counts, so should be taken as only the minimum that these pools would have recorded this year. ***For Fenns & Whixall, pool* areas *are used instead of pool* sizes*, and so many be not be directly comparable to the Cumbrian sites.*

This would suggest that the Foulshaw Moss population is at least as strong as the Scaleby Moss population from which it was reintroduced; the same will hopefully be seen in time with the Drumburgh Moss exuvia counts. Data published by David Clarke in 2014 shows that Scaleby Moss has remained in a similar range to the results from 2007-2014, with an average of 730 exuviae (standard error confidence interval of 574-894) per 100m^2 pool.

We can also see that, so far as our survey data allows, that the Fenn's & Whixall Mosses are not in as strong a position as the Cumbria ones. This may be a result of sampling bias, which highlights the limitations of white-faced darter surveys which are restricted to a limited number of safely accessible bog pools. This stresses the need for further preservation of these habitats and conservation action to secure the future of this rare species.

If a future North Yorkshire reintroduction project was to go ahead, these results show us that Foulshaw Moss would make a good candidate: it is the nearest stronghold for white-faced darter to our sites, and it has a strong population. Scaleby Moss is already involved in other reintroduction sites, so it may not be practical to drawn from this population in the short-term. Drumburgh Moss is still in its growth-phase, and it is unlikely it would be considered as a donor in the near future. Fenn's & Whixall Mosses are further away than the Cumbria sites, and further investigation would be needed to ensure that these populations are stable enough to withstand any reintroductions.

Discussions with groups who have led previous reintroductions have advised that it is ideal to consider translocations from more than one donor population. The reasoning is to increase the genetic diversity of the *L. dubia* population on a translocation site, which would then have a higher resilience to environmental pressures such as to climate change and diseases. Therefore, it seems likely that a North Yorkshire reintroduction would require further investigation into the Fenn's & Whixall population stability, and we could also look closer to home to Cheshire.

PART 4: DRAGONFLY POND CREATION

In Part 2 we made a case for creating new wildlife ponds for dragonflies on Swarth Moor, which would create additional habitat for the existing peatbog dragonflies on this site, and, if designed correctly, could also be made to support the habitat requirements of white-faced darters.

In Part 3 we created a baseline for the Odonata species on Swarth Moor before the restoration in the fen area and the creation of new ponds. We also showed that peat restoration creates habitats for dragonflies in the upland blanket bog sites, and that the man-made 'newt' ponds on Swarth Moor support most of the species present on site.

In Part 4, we describe how we designed the dragonfly ponds for Swarth Moor.

4.1. DESIGN OF PONDS

As discussed in Part 2, the location which met the habitat requirements of acidity, peat depth, water quality, and vegetation structure converged on a candidate area for ponds, as shown in Figure 4.1.

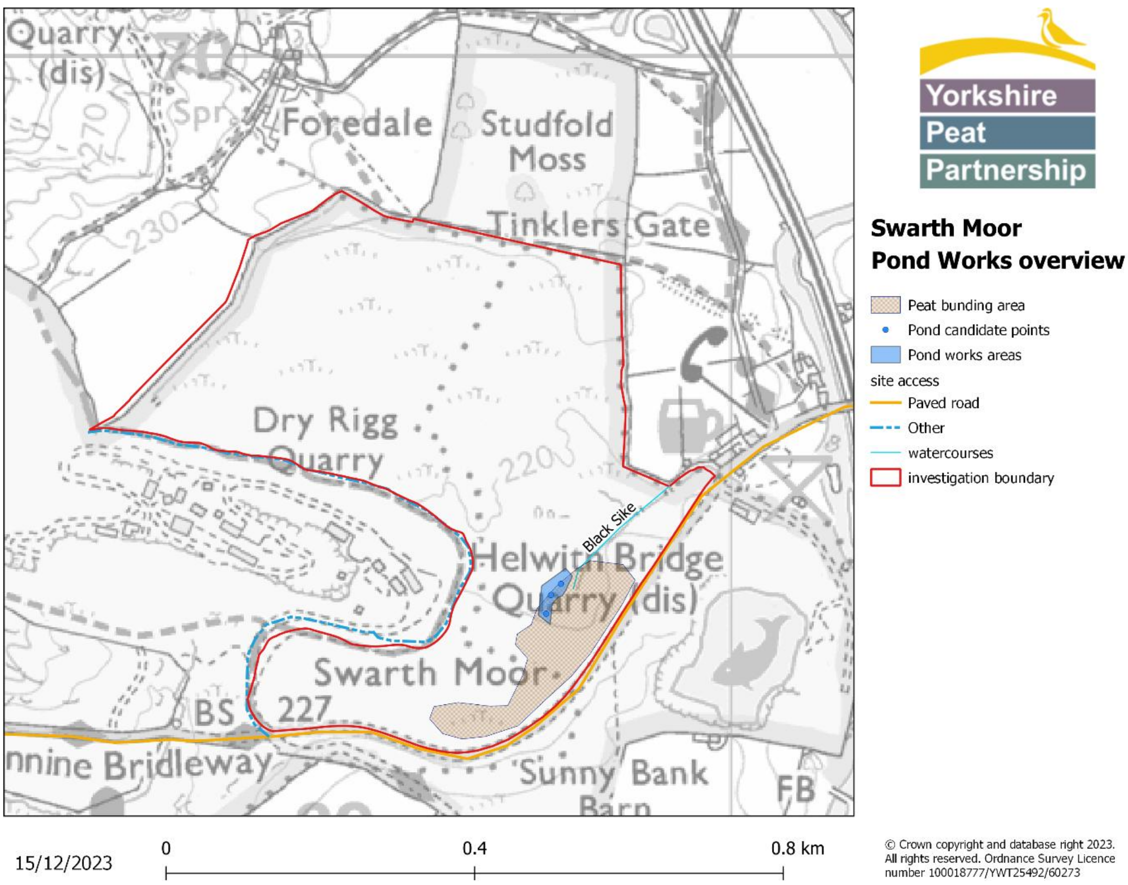

Figure 4.1 – Location of 3 new dragonfly ponds on Swarth Moor within peat-bunding area for restoration.

From Part 1 Table 1.1 and Figure 1.13, we can design the dimensions which would be most favourable for white-faced darters. This would give us a pond size of around 70m^2, a pool depth aiming for 1m deep and a pond density of 10 pools for 1 km^2, which for Swarth Moor at 29 hectares would be about 3 ponds.

We wanted to design the ponds to be supportive of wildlife in general on this site, so we built a lot of the design and location of the ponds around resources from the Freshwater Habitat Trusts website, for example, to ensure the habitat was in a location with acceptably low levels of nitrate and phosphate and electrical conductivity. We also took their advice on creating very shallow (0-10cm) margins of each of the ponds, as there are many invertebrates which will only use this area and so it is particularly important to build into wildlife ponds to support a maximum biodiversity.

Lastly, we wanted to design the ponds to be supportive of dragonflies already present on Swarth Moor. In particular, we knew from the surveys that Swarth Moor supports breeding populations of common hawker, black darter, and emerald damselfly, and these three species have had the largest declines as recorded in the State of Dragonflies Report 2021. Therefore, we wanted to design the three ponds with these three important species in mind.

For example, emerald damselflies prefer smaller, shallower ponds and prefer a high proportion of the pond circumference to be vegetated with marginal vegetation such as rushes and emergent vegetation. They were spotted on site making particular use of the bulrushes and *Juncus* near to the fen, and so a pond was created near to this area amongst more rushy vegetation, with a depth <50cm and a size around 40-60m^2. The vegetated turves where then laid down into the pond to kick-start the emergent vegetation. Conversely, the common hawker prefers a larger, deeper pond which has some marginal vegetation, so this pond was created up to 100m^2 in area and 70-80cm deep in the middle (see Appendices for full details of pond design in “YPP Technical Specification - Dragonfly Pond Creation”).

4.2. INSTALLATION OF PONDS

Conservefor Limited, the Bentham-based conservation and restoration contractor, were assigned to deliver the peat restoration and pond creation works for Swarth Moor in 2024. Conservefor were part of first phase of peat restoration in 2020 who constructed the cell-bunding and have a strong portfolio of delivering upland and lowland peat restoration projects across the north of England and Scotland.

Figure 4.2 – Photographs taken in October 2024 of the new dragonfly ponds. A) Pond being constructed by Conservefor operator Gordon Charnley, B) the largest pond, designed around the common hawker, C) the medium-sized pond, designed around the black darter, and C) the smallest pond, designed around the emerald damselfly. Photo credits: Alexandra Smith, Jessica McMaster, YPP.

In October 2024, the contractor constructed the three dragonfly ponds in the target area (see figure 4.2a). They rapidly seemed to attract the dragonflies on site; in fact, a common darter pair were seen copulating and egg-laying while the ponds were still being created! At this early stage it is too soon to say if the target species will colonise them, but this certainly seems like a good sign.

PART 5: HABITAT SUITABILITY SURVEY POST-WORKS

After the three new dragonfly ponds were completed, we needed to return to re-assess Swarth Moor for its updated habitat suitability for white-faced darters.

The factors which would need reassessing following works were: pH, nitrate and phosphate pollution levels, aquatic invertebrate biodiversity, and water depth measurements of the waterbodies. As we returned in early March, it was worth taking a baseline for dragonfly nymph presence in the new ponds and across the restored area too.

The survey area was more targeted than in 2023/24 (Part 2) and was restricted to one grip (‘Black sike’) and one gully which had been blocked, the new dragonfly ponds, two of the great-crested newt ponds, and one fen pool.

5.1. HABITAT FIELD SURVEY 2025 RESULTS

The pH measurements were very similar to those taken in the habitat survey in 2023 (see Figure 5.1). It is reassuring to check that the pH in the new ponds is acidic enough for white-faced darter, and at this acidity it remains unsuitable for larger predators such as fish. (For raw data, see Appendices).

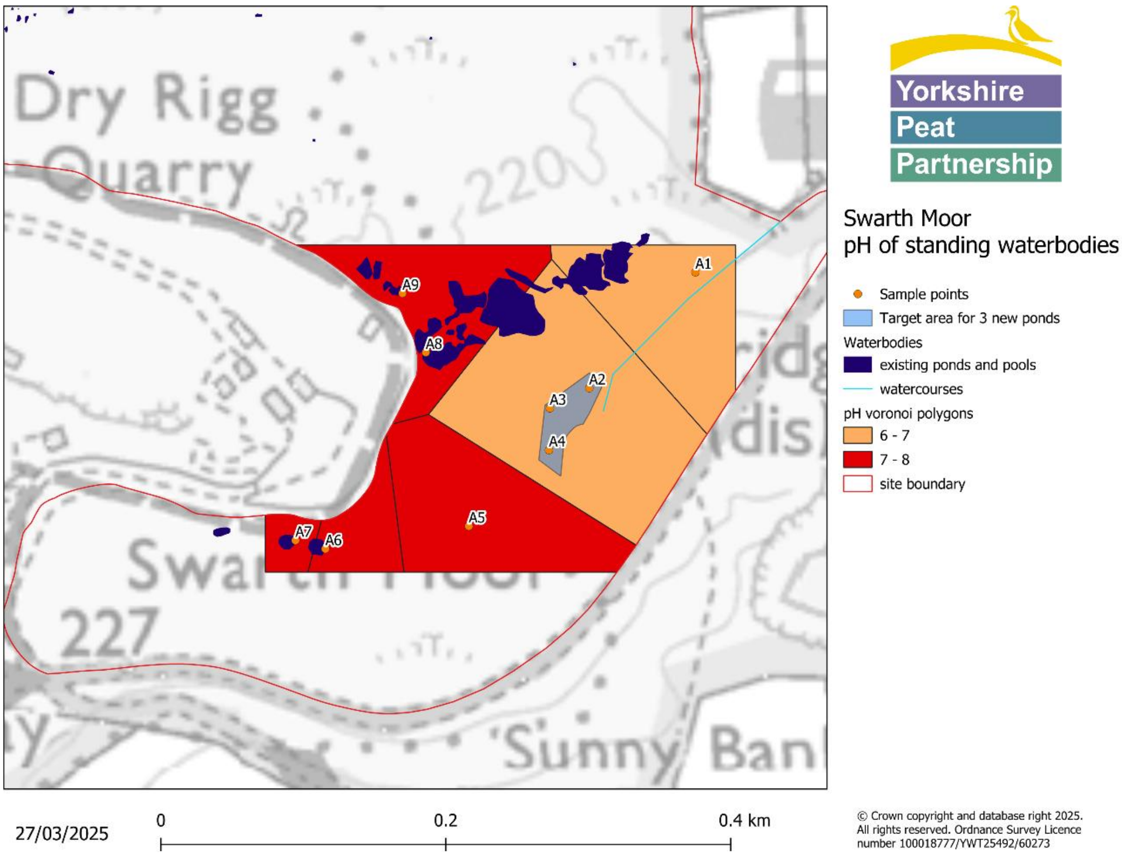

Figure 5.1 – pH measurements as Voronoi polygons across the lagg fen and fen.

The maximum water depths of the three new ponds were constructed as: 40cm, 50cm and 70cm.

For both nitrate NO_3 and phosphate PO_4 in all samples tested, including the new dragonfly ponds, the results were clear so have the lowest reading possible (Figure 5.2). This tells us that the new ponds have no evidence of nitrate or phosphate pollution, which is ideal for wildlife ponds.

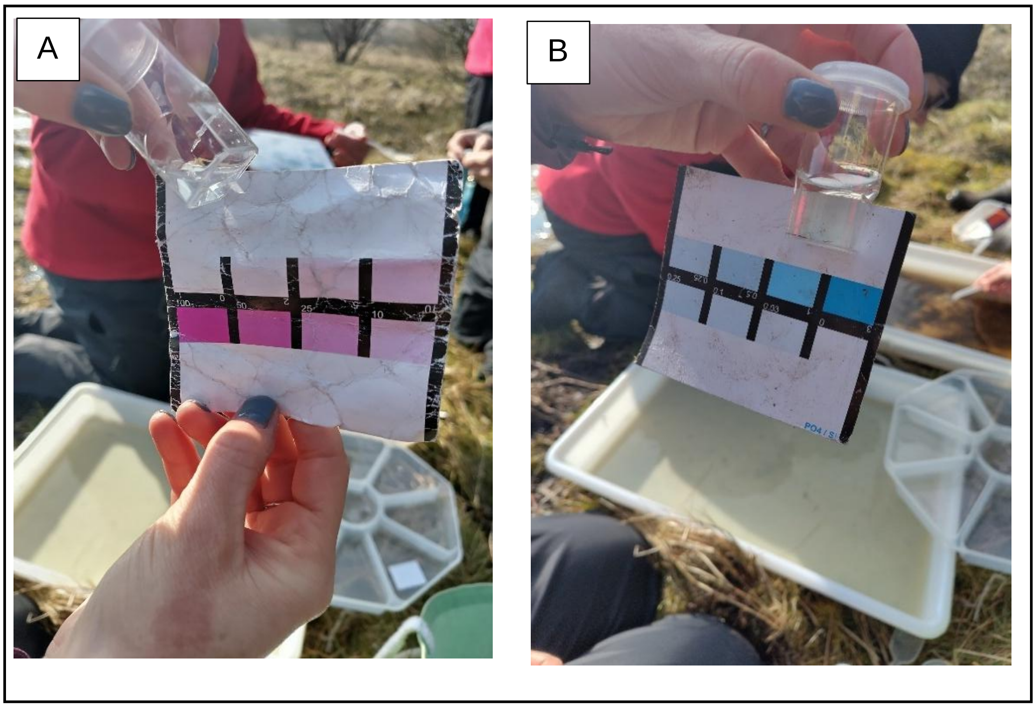

Figure 5.2: A. Nitrate test showing approx. 0ppm NO_3, B. Phosphate test showing approx. 0ppm PO_4.

5.2. AQUATIC INVERTEBRATE SURVEY 2025 RESULTS

The repeat aquatic invertebrate survey was carried out in early March 2025. When comparing this to the baseline survey in 2024 it should be noted this was done in mid-April, which may have affected the comparability of the results. Because of the earlier timing, some taxonomic groups will not have emerged and will not be recorded in repeat survey. For example, we did not record a single mollusc in 2025, whereas in 2024 molluscs such as freshwater snails were recorded in over half of the samples, so at the least this will have reduced the taxonomic groups by one. Freshwater snails are known to migrate deeper into waterbodies in the colder months. The total individuals recorded may also have been affected by the colder weather; in the great crested newt ponds, there was a small reduction in total invertebrates counted, and since no work occurred on or very near to these ponds, the individual counts may be expected to be slightly lower for March 2025 as a result of colder weather and the earlier date.

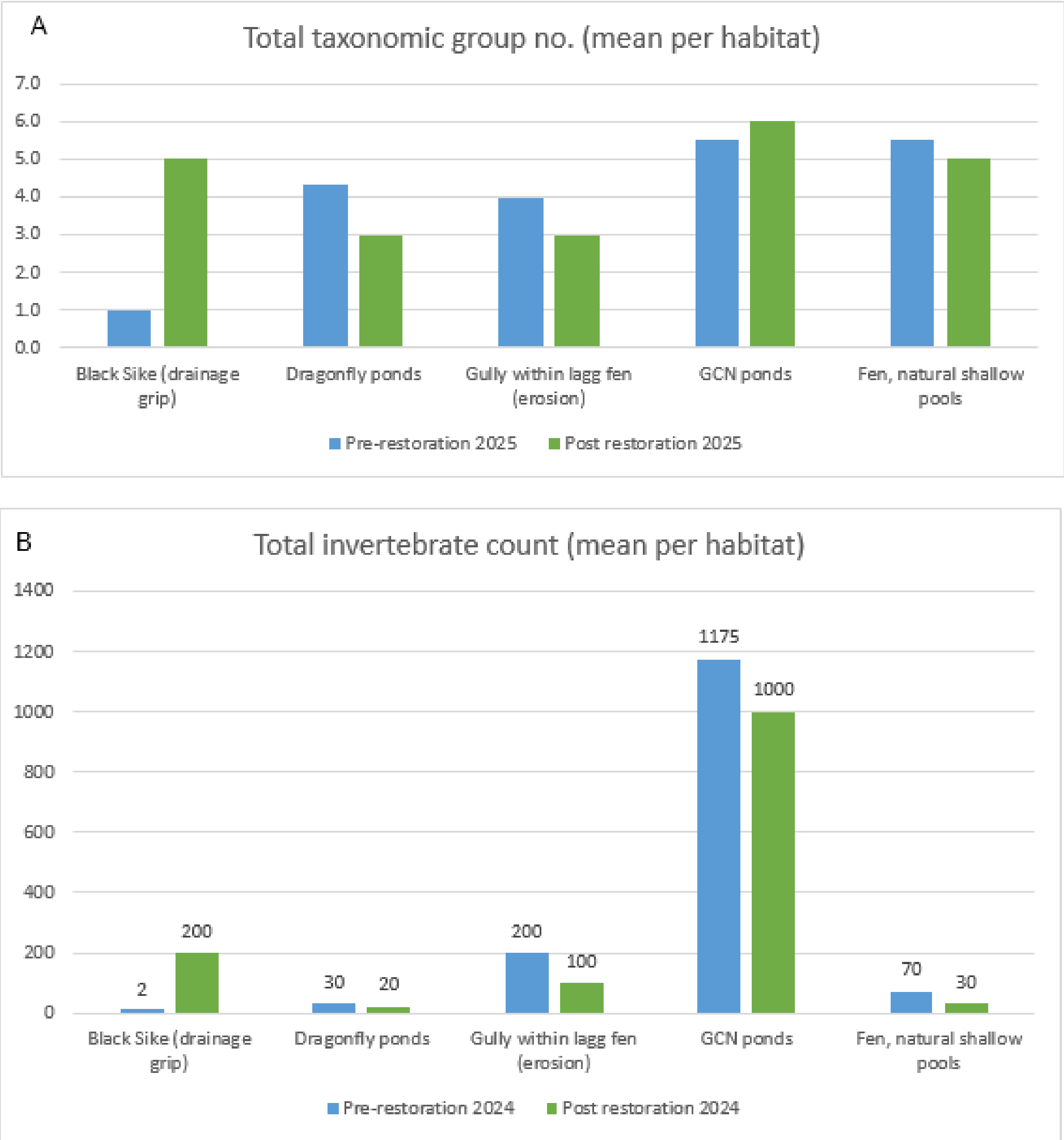

Figure 5.3 – Bar chart comparison of aquatic invertebrate survey results from April 2024 'Pre-restoration' and before pond creation, and March 2025 'Post restoration' and after the pond creation.

The most striking difference for both taxonomic groups and total invertebrate counts was for Black Sike, the drainage grip (Figure 5.3). Before the restoration, this grip was actively draining the site, and had very little water present, and consequently just two beetles were counted. Between these two timepoints, this grip had been blocked with stone and timber sediment traps, which have filled lower down with pools of water. These pools of water are now providing a new aquatic environment for much more invertebrate biodiversity.

The other habitats are not significantly different for the pre and post-restoration. It will be very informative to return to some of the new ponds and restored erosion channels in future to track the impact of peat restoration on aquatic biodiversity.

5.3. ODONATA NYMPH SURVEY MARCH 2025 RESULTS

In addition to the repeat aquatic invertebrate survey, we carried out a survey of any Odonata species recorded in the samples on the same date in March 2025. The same caveats need taking into consideration that March is typically quite early to be recording dragonfly nymphs, just as with aquatic invertebrates, and not all species will be present in this survey.

As such, the only ponds which recorded Odonata were the deep great-crested newt ponds. No nymphs were recorded in the new dragonfly ponds, or any of the other waterbodies sampled. This survey was taken just 5 months after the new dragonfly ponds were constructed, and October is very late in the breeding season for Odonata, so clearly this is too early for nymphs to appear in the new ponds. Nevertheless, a pair of common darters were seen ovipositing into one of the new ponds while they were being constructed, so we look forward to surveying next year.

The dragonfly nymphs recorded from the great crested newt ponds were as follows: Azure damselfly (*Coenagrion puella*), Blue-tailed damselfly (*Ischnura elegans*), Common blue damselfly (*Enallagma cyathigerum*), Large red damselfly (*Pyrrhosoma nymphula*), and black darter (*Sympetrum danae*) (For raw data, see Appendices).

5.4. DISCUSSION

The results of the habitat and aquatic invertebrate surveys, reveal that the fen area is within range for the pH, and has no evidence of nitrate or phosphate pollution. The increased water depths in the bunding and dam blocking are clearly providing more aquatic biodiversity in certain areas, but it is too early to tell if the new ponds will provide the aquatic biodiversity for dragonfly nymphs to feed. However, the abiotic conditions are optimal for aquatic life more generally.

We have taken the potential habitat suitability of the target site from Part 2.6 and created ponds which have the chemical conditions for white-faced darter. Nearby man-made ponds have the aquatic invertebrate biodiversity for dragonfly nymphs to feed, and the surrounding peat restoration has resulted in an overall increase of aquatic invertebrate abundance and taxonomic diversity. Therefore, in time there is reason to believe that invertebrate prey will colonise the new man-made dragonfly ponds. In Part 6, we develop the Habitat Suitability Index model further using the results of the UAV surveys.

PART 6: HABITAT SUITABILITY INDEX

6.1 AIMS

The existing methodology for white-faced darter habitat suitability surveying contains several subjective metrics, which limits surveying capacity due to the requirement of trained staff. We established a process for creating a Habitat Suitability Index (HSI), which takes as many aspects of the habitat suitability survey as possible and derives a measure of the habitat from spatial data collected via aerial survey or unmanned aerial vehicle (UAV). The HSI enables prioritisation of on-ground survey staff time, by identifying high value areas of sites and thus limiting the amount of area needing to be covered.

The HSI will also allow for the prioritisation of sites that are potential white-faced darter translocation sites by quantifying the habitat suitability at a desktop stage, using an UAV to survey the site, or by using purchased aerials. Additionally, habitat for white-faced darter is hard to traverse, and in some existing populations there may not be ready access to all breeding pools for monitoring. By remotely quantifying valuable breeding areas we may be able to improve population estimation accuracy without changes being made to current monitoring practise.

6.2 SURVEY

The UAV surveys for Swarth Moor were conducted on the 5th September 2023 'pre-works' and on the 28th of February 2025 'post-works'. The UAV survey for Fenn's & Whixall Mosses was conducted on the 18th June 2024.

6.3 HABITAT SUITABILITY INDEX DEVELOPMENT

The HSI aimed to quantify white-faced darter habitat requirements, as follows: pool area, pool access, tree roost access, shrub roost access and emergent vegetation presence. Pool geometries and pool vegetation cover are also accounted for in the HSI, but this needs to be derived outside the methodology through automated means (i.e. image classification). Alternatively, these can be manually digitised, a process that is much more accessible.

The aspects of habitat suitability are quantified from: the input data, a set of pool geometries with vegetation cover, geometries for the site boundary, and a 0.5m DSM. The processes for each aspect are detailed below:

1. **Pool area** – WFD show a preference for certain sized pools. Directly calculated from the input pool geometries, with sub-optimal pool geometries are removed.
2. **Pool access** – Flight distance around the pool geometries is calculated as this represents access and density of the pools, which are important for both food and breeding.
3. **Tree roost access** – Roosts are an important aspect of WFD ecology. Tree height is determined through a 'difference from mean' calculation. Trees of a suitable height are isolated, and flight distance around these trees is calculated.
4. **Shrub shelter access** – Shrub height is determined through a 'difference from mean' calculation. Shrub cover that is suitable height as according to the information provided in the literature review is isolated, and flight distance around these areas is calculated.
5. **Emergent vegetation** – Suitable emergent vegetation is determined through a 'difference from mean' calculation, and any pool that does not overlap with suitable emergent vegetation is removed.
6. **Pool vegetation cover** – WFD breed in pools with an average *Sphagnum* cuspidatum cover of between 49%-100%. Pools are scored based on their vegetation cover, and pools with optimal vegetation cover are scored higher.

6.4 RESULTS

The result produced by the HSI is a Georeferenced raster displaying areas of relative habitat suitability. To test the HSI it was run on a highly productive area of Fenn's and Whixall mosses, a site with a well-established population of white-faced darter. The result, Figure 6.1, highlights a traditionally productive monitoring pool, along with many unmonitored pools in the vicinity. The HSI for this area of Fenn's and Whixall had an average score of 96.07, with a standard deviation of 27.08, with the area directly surrounding the monitored breeding pool having an average of 114.59, and a standard deviation of 28.39.

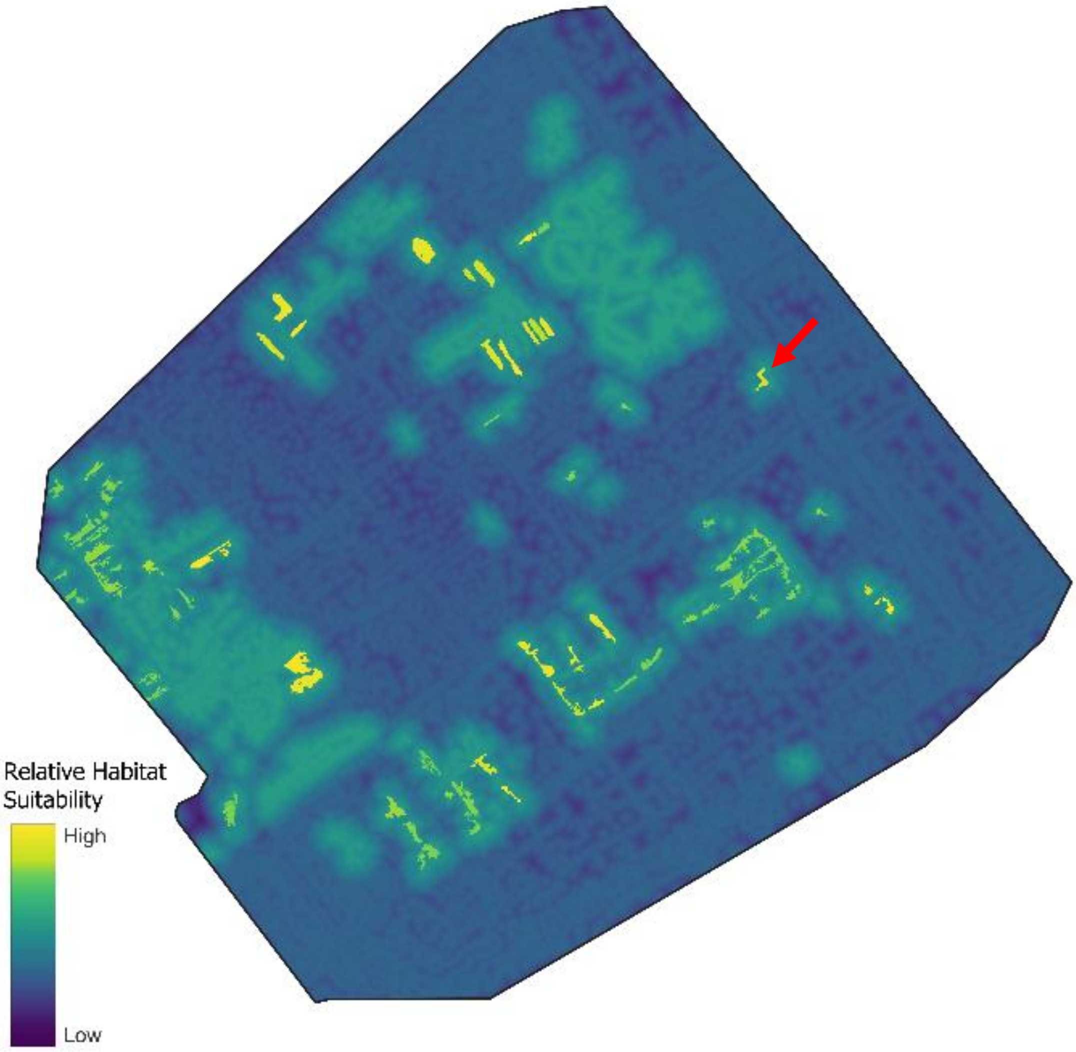

Figure 6.1 - Test example Habitat Suitability Index (HSI) result from Fenn's and Whixall. Location of a traditionally productive monitoring breeding pool indicated with arrow.

The HSI process was run on the pre- and post-intervention UAV survey data for Swarth Moor, a candidate white-faced darter translocation site. The pre-intervention survey highlighted three areas of high habitat suitability: the previously bunded area in the north of the site, the great crested newt pools in the south, and the pools surrounding the drainage system leading into the Black Sike (Figure 6.2), and the post-intervention survey highlighted the creation of new habitat suitable to white-faced darter, formed on the south-eastern edge of the site (Figure 6.3). The change in habitat suitability can be seen in Table 6.1.

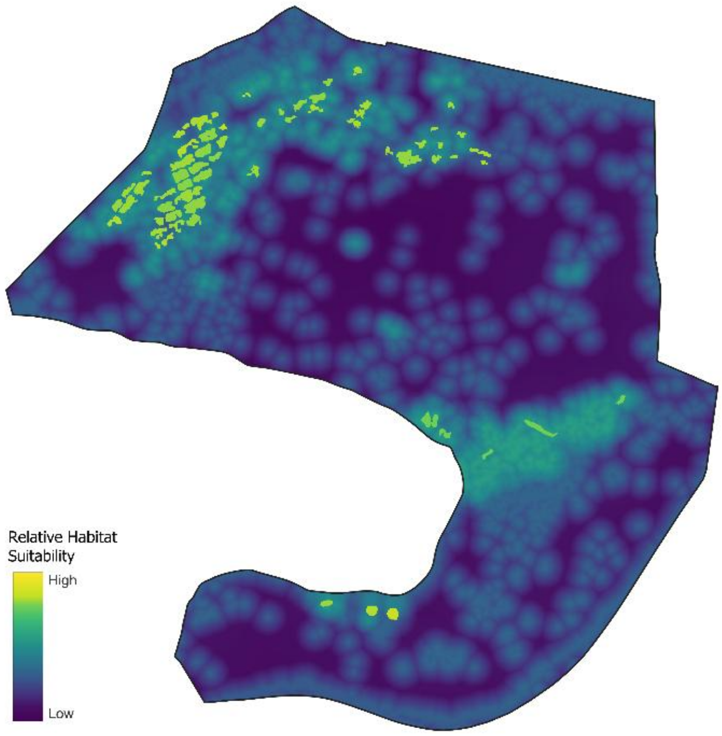

Figure 6.2 – Result of the 2023 Pre-intervention Habitat Suitability Index.

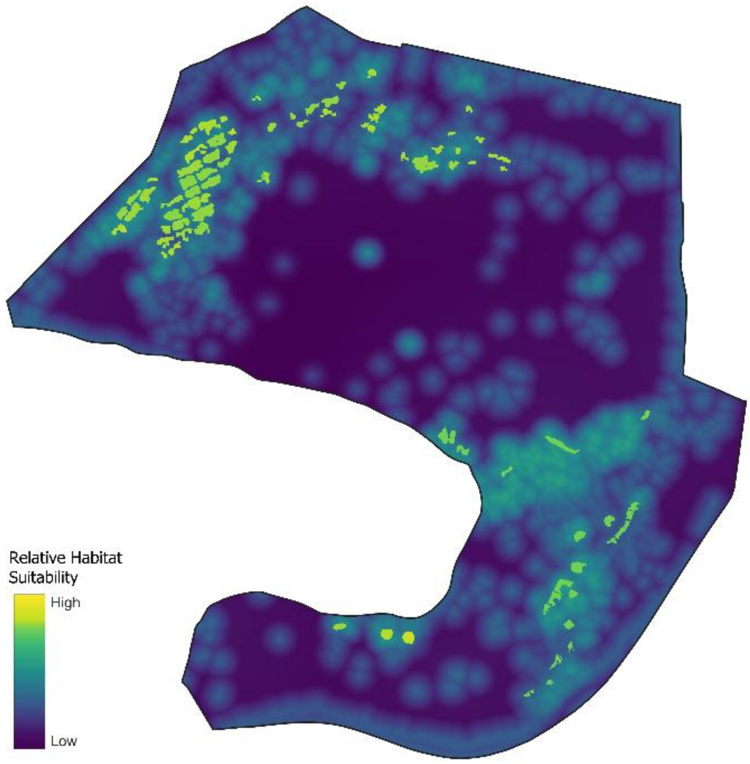

Figure 6.3 – Result of the 2025 Post-intervention Habitat Suitability Index.

The results of this showed that the bunded areas and new ponds were holding significant amounts of water. It should be noted that since the initial Swarth Moor UAV survey was completed in the middle of Summer in 2023 that this 2025 repeat survey isn't a direct comparison. However, there is now significant change in the amount of water on other areas of the site, suggesting that this new water accumulation isn't just a product of a wetter climate.

A spatial difference plot was made by subtracting the pre-intervention HSI from the post-intervention HSI, shown in Figure 6.4. This difference plot highlights the uplift in habitat suitability around the new works. It also shows a general decline in habitability across the site, however this is an unfortunate side effect of the pre- and post- intervention UAV surveys being conducted at different times of the year; June and February accordingly. This effect is almost entirely caused by reduction in tree height, due to the trees on site still lying dormant when the post-intervention survey was conducted.

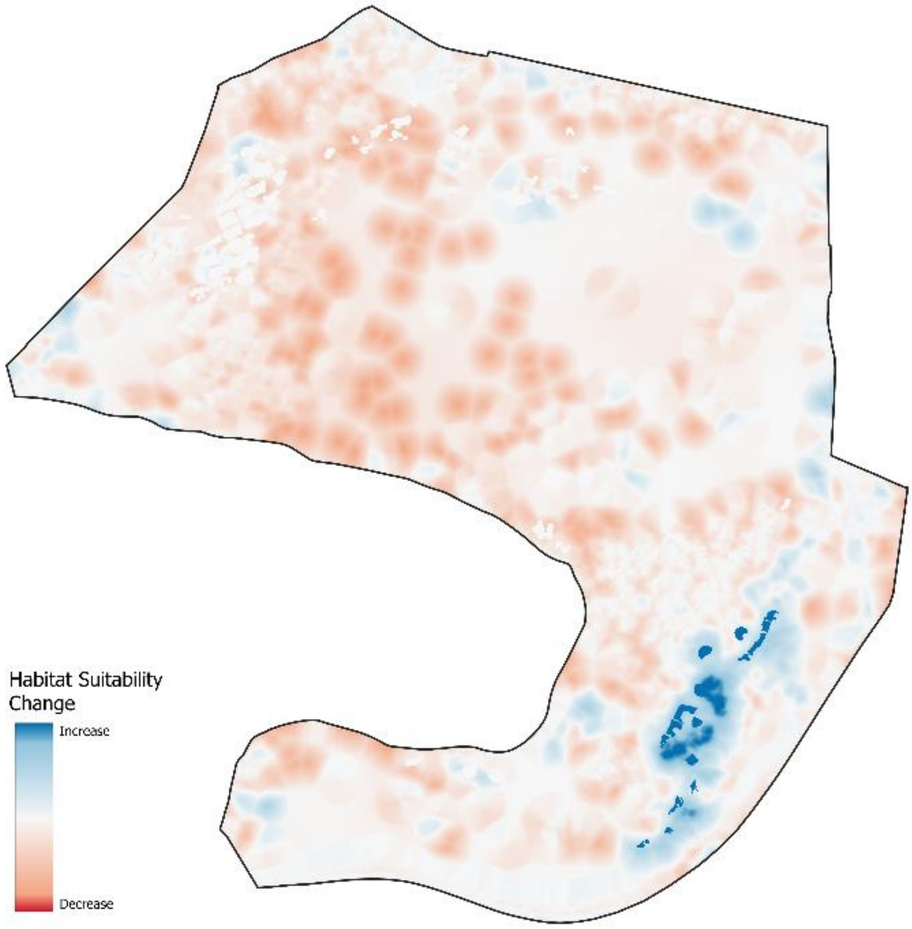

Figure 6.4 – Difference plot of Swarth Moor comparing the pre-intervention HSI from the post-intervention HSI

Initially the HSI process aimed to identify the pool cover of *Sphagnum cuspidatum*, white-faced darters' favoured breeding vegetation. One challenge identified through the process is that vegetation identification through remote imagery was flawed. Anecdotally, the breeding pool mentioned in the Fenn's and Whixall Mosses example (Figure 6.1) had ceased being productive in the year prior to our UAV survey of the area, with a likely reason being an outbreak of algae in the monitoring pool. The algae, present in the UAV survey imagery, looks superficially similar to the *Sphagnum cuspidatum* as identified through image classification. The consequence of this is the inability of the HSI to differentiate between the favoured *Sphagnum cuspidatum* and other water-borne vegetation, meaning this habitat metric will still be required to be collected alongside other ‘on-site’ metrics such as water quality and peat depth.

Despite the limitations, the advantage of the HSI process is that it is easily used without having to physically access a site. YPP has a large amount of stored UAV data on with the HSI can be run, enabling YPP to identify which sites in its operational area have comparatively better habitat for White-Faced Darter. This means that YPP can better prioritise sites for the purposes of translocations and habitat improvements. Another advantage is that on-site surveying can be more targeted. By identifying areas of a site which have better suitability, survey transects can be optimised to cover these areas, making the survey more likely to catch present individuals. While this HSI was developed with white-faced darter in mind, the same principles can be used to make an Index specific to other species, or even a more generalised Index that captures the habitual preferences of a group of species.

6.5 DISCUSSION OF SUITABILITY FOR WHITE-FACED DARTERS ON SWARTH MOOR POST-WORKS

The works on Swarth Moor saw an increase in habitat suitability around the works area, but the viability of this area for white-faced darter still falls short in several aspects. In Table 6.1 it can be seen that the Index for the area directly surrounding the works has seen an increase in suitability, but it is still less than the suitability of an established white-faced darter site like Fenns and Whixall Mosses, as seen in Table 6.2. The main contributing factor for this difference is the lack of established *Sphagnum cuspidatum.* This indicates that the works area requires time for the appropriate species to establish and develop into the habitat that white-faced darter prefers.

	Pre-intervention survey		**Post-intervention survey**	
	Mean	Standard deviation	Mean	Standard deviation
Whole site	66.60	36.19	56.74	39.71
Intervention area	65.02	22.03	81.77	33.49

Table 6.1: Change in Habitat Suitability Index for Swarth Moor between the June 2023 and February 2025 survey.

	Pre-intervention survey	
	Mean	Standard deviation
Whole site	96.07	27.08
Intervention area	114.59	28.39

Table 6.2: Habitat Suitability Index on Fenns and Whixall Mosses.

For full protocol for Habitat Suitability Assessment with the field and UAV parameters, see Appendices.

PART 7: SPECIES DISTRIBUTION CLIMATE MODELLING

In the previous section, we have developed a method for identifying suitable sites for white-faced darter at a local level on a site-by-site basis. In this next section, we look at modelling the suitability of the weather and climate conditions for white-faced darter at a county level and across Great Britain.

7.1 BACKGROUND

Species Distribution Models (SDM) are used to assess suitable habitats for a translocated species by predicting environmental conditions that support survival and reproduction. It aids in conservation planning by providing an objective assessment, helping to identify sites that will encourage long-term viability and avoid risks.

An SDM was made to explore the areas of suitable climate for white-faced darter in Yorkshire Peat Partnership's area of operations, as well as across Great Britain as a whole. Further modelling was done to see what climate suitability may look like under future conditions. Other species distribution models exist for white-faced darter with more accurate and descriptive input data; however, these data can only describe current conditions and are therefore unsuitable for future modelling, so the modelling exercised only used bioclimatic variables available through WorldClim (http://www.worldclim.org; Hijmans et al., 2011).

7.2 METHODOLOGY

WorldClim produces different future climate projections, made using CMIP6 models, with the climate projections differing under different Shared Socioeconomic Pathways (SSPs). For this exercise we chose to use SSP 2-4.5, which represents a 'Middle of the road' pathway, representing a continuation of historic socioeconomic reaction to climate change, with atmospheric carbon peaking around 2040 before declining, with an average warming of 2°-3°C above pre-industrial levels. The future prediction window used was 2020-2040. This was chosen over other prediction windows as it covers the immediate challenges presented to any translocated population in the near future, as well as covering the time period for the 30by30 goals set out by the Global Biodiversity Framework.

MaxEnt was chosen as a method, as it is widely used for this type of modelling, and it was accessed through the DISMO package for R. The following variables were chosen, as they had the highest contribution to the distribution model: annual mean temperature, isothermality, temperature annual range, mean temperature of coldest quarter, precipitation of wettest month, precipitation of driest month, precipitation seasonality, precipitation of warmest quarter, precipitation of coldest Quarter, and elevation above sea level. Training points were taken from GBIF (https://www.gbif.org/), using *L. dubia* records from the UK. The training points were cleaned by removing records without an accurate location, as well as removing duplicate records. The model produced an AUC of 0.9627077, suggesting good fit, however due to the limitations of the input data this isn't fully descriptive of possible habitat suitability for white-faced darter.

7.3 RESULTS OF CLIMATE MODELLING ON WHITE-FACED DARTER SUITABILITY

When the model is applied to current climate conditions, we can see significant hotspots around current white-faced darter populations as expected (The Scottish Highlands, Arnside, Fenn's and Whixall moss), due to sightings in these populations being used in the training data (Figure 7.1a). We can also see large areas of suitability surrounding these populations, suggesting that the spread of these populations is not currently being limited by climate.

The in-set graphic shows an overlay of Yorkshire Peat Partnership's area of operations (Figure 7.1b). The model suggests that there is a corridor of moderately suitable climate following the Eastern foothills of the Yorkshire Dales, with further suitable climate found in the foothills of the North York Moors. Peatland restoration sites within these bands of habitability can be identified for future Odonata habitat improvement.

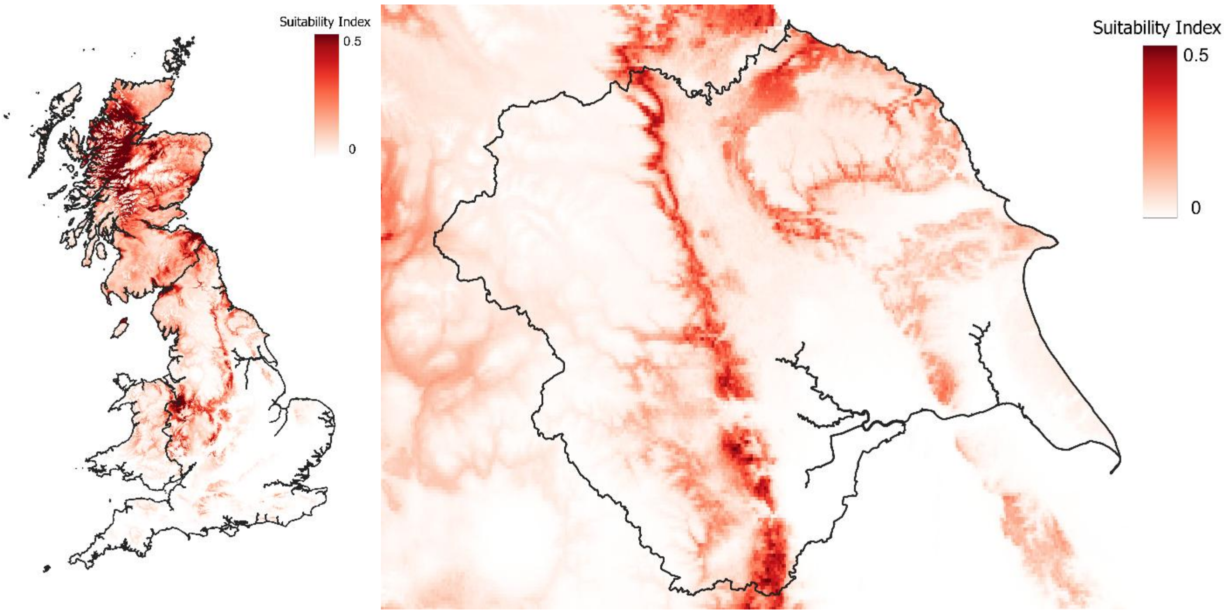

Figure 7.1 - The model for white-faced darters current distribution under current climate conditions a) across Great Britain, and b) across Yorkshire Peat Partnership's area of operations.

When the habitat model is applied to future climate conditions up to 2040, it is immediately obvious that there is a dramatic reduction in suitable climatic conditions, seeing dramatic reductions throughout GB (Figure 7.2a). There are some areas where the habitability increases, namely in central Wales, and the far north of Scotland, but these areas are greatly reduced in area compared to the current suitable climate extent. This model also shows a loss of white-faced darter suitability across much of its current Northern England populations, including Cumbria and Shropshire, and across much of Yorkshire Peat Partnership's area of operations (Figure 7.2b).

It should be noted that while this species distribution model aims to map the relative climate suitability, it does not take into account habitat suitability. Because white-faced darter as a species is reliant on wet habitats, the distribution of the species closely follows areas which receive high amounts of precipitation. However, a shortcoming of this approach is areas that have low precipitation, but remain wetter regardless due to geographical reasons, will have an artificially lower climate suitability scoring. Coupled with the resolution of the datasets available (approx. 500x500m) this means that small pockets of lowland raised bogs may be overlooked as being climate-poor, but in reality, they may be well-suited for white-faced darter. While this model does give a measure for comparing the climate suitability for geographically distinct sites, a given site with good habitat shouldn't be overlooked because it has a poor climate scoring.

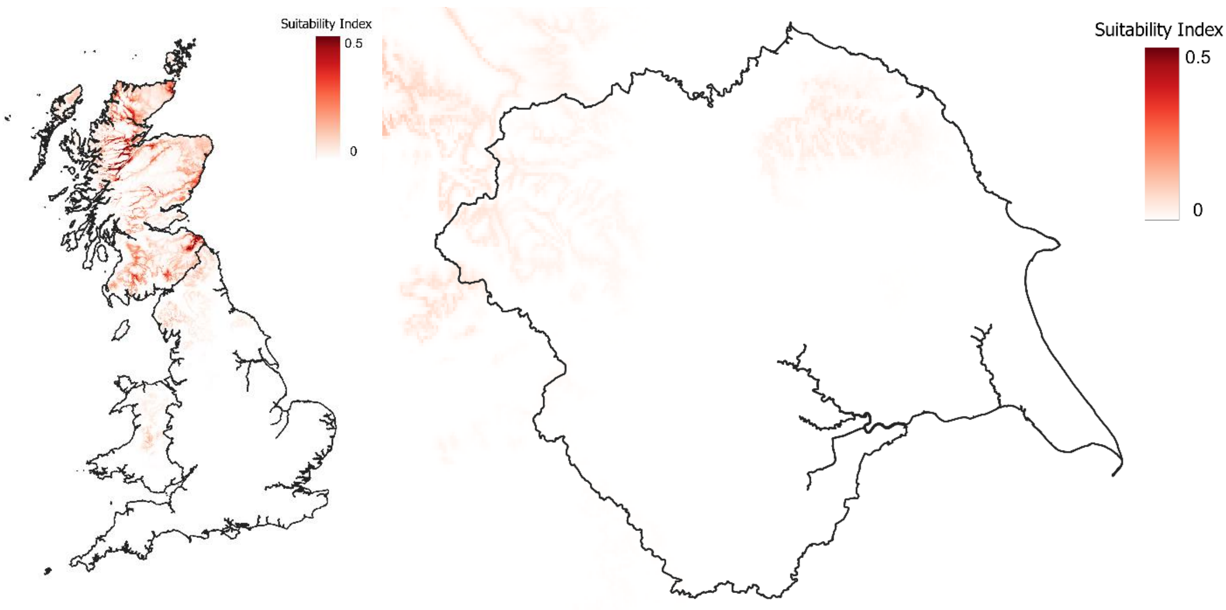

Figure 7.2 - The model for white-faced darters distribution in future climatic conditions SSP245 in 2020-2040 a) across Great Britain, and b) across Yorkshire Peat Partnership's area of operations.

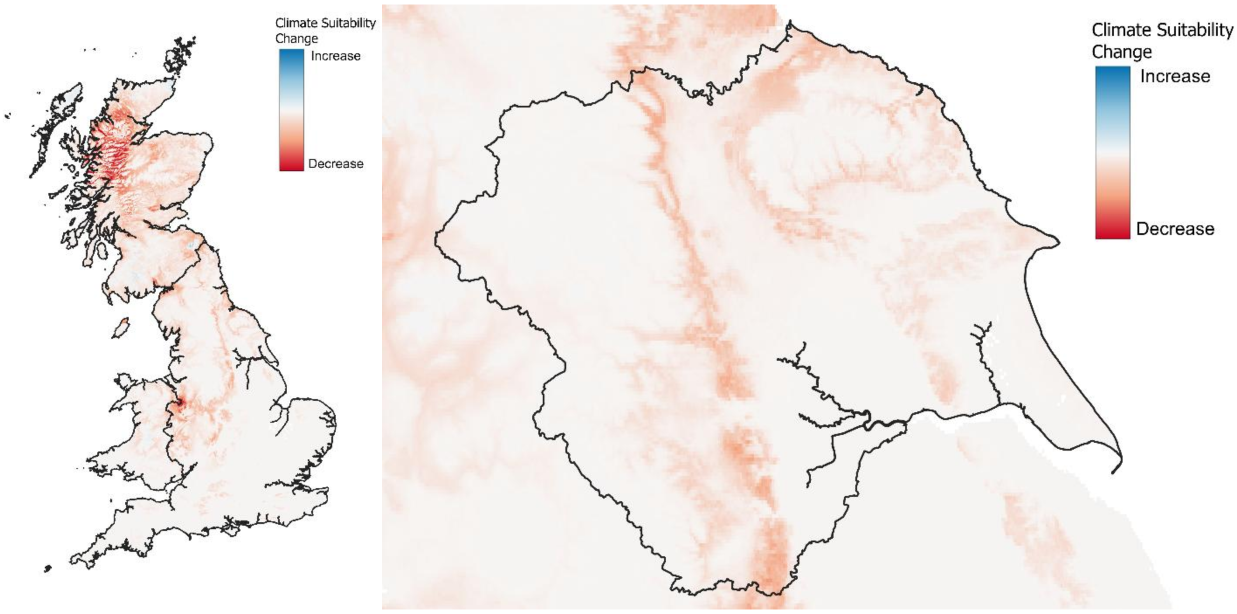

Figure 7.3 - Climate suitability change from current conditions to future conditions a) across Great Britain, and b) across Yorkshire Peat Partnership's area of operations.

	Present Climate Suitability	**Future Climate Suitability**
Swarth Moor	0.029	0.004
Austwick Moss	0.067	0.004
Fenns and Whixall Mosses	0.908	0.001
Foulshaw Moss	0.352	0.000
Scaleby Moss	0.372	0.000
Hatfield and Thorne Moors	0.000	0.000
Scottish Highlands	0.588	0.120
Flow Country	0.362	0.107

Table 7.1: Climate suitability scores of various sites.

In Figure 7.3 and Table 7.1 it can be seen that there is a widespread decline in climate suitability across the UK. If this distribution model is correct, it is a strong indication that white-faced darter will undergo extreme climate pressure in the coming decades, and while it is unlikely that established populations will immediately disappear, it does highlight the need for regular monitoring and population management.

7.4 DISCUSSION OF CLIMATE SUITABILITY MODELLING

The results of the Future Climate Suitability modelling provides an indication of future stressors to white-faced darter populations. It is not, however, without issues. A principal concern is that climate projections are speculative, and while they can provide guidance they are by no means a guarantee. Another limitation is input data. Other SDM models exist for white-faced darter and take into account more aspects of their ecology than this model has, due to the unavailability of future data for those aspects and so this model's predictions of future distribution aren't comprehensive.

Habitat, and habitat management, play a significant part in the success of a threatened population, and should be given consideration in addition to climate suitability. If a prospective translocation site has high quality habitat with a structured regime for habitat management such as at Fenn's & Whixall Mosses, or suitable but currently degraded habitat undergoing restoration with a structured restoration management plan such as in Hatfield and Thorne Moors, this habitat may make up for any climate pressure endured. Conversely, there are areas with high climate scoring but no suitable habitat for example currently in the foothills of the Yorkshire Dales and North York Moors, presenting an opportunity to habitat improvements to be made in the area to aid in building resilience for the species.

PART 8: PROJECT ENGAGEMENT

8.1 VOLUNTEER ENGAGEMENT

The project's Swarth Moor dragonfly surveys could not have been achieved without the help of our amazing team of 'Peat Dragonfly Survey' volunteers.

The volunteers supported on all the dragonfly surveys to Swarth Moor, and to the uplands of Fleet Moss as well. In total the volunteers put in 3,336 hours over the whole dragonfly season in 2024.

At the beginning of the season, our 8 volunteers came on a training day with Keith Gittens. After this, staff were present on the dragonfly surveys to help build the volunteers' knowledge and skills over the season. Considering the fact that our YPP staff had only been trained the season before in Odonata identification, by the local county recorder Simon Joseph, we all became proficient in dragonfly species identification by the end of the season.

After each survey, one of the volunteers took the paper survey form home and they would then upload the data onto a YPP dragonfly digital form on the KoboToolbox (www.kobotoolbox.org) platform. We could then manage the survey data coming in during the season, and at the end of the season it was straight forward enough to download this directly into the format which iRecord takes its data in, so that as soon as the county recorder had verified our records it could be submitted straight to iRecord. This process worked very well for us, enabling our volunteers to have the agency to directly upload the data to our database. This then streamlined the process for the county recorder, allowing it to be uploaded straight to iRecord's national database. This is also an advantage for the scope of volunteer-led action, because it means the volunteers have ability to carry out dragonfly surveys without staff being present – and when surveys are so weather-dependent, this means volunteers are not held back by staff's work-week timetables.

Now that the Species Recovery Programme funding comes to an end in early 2025, YPP are seeking further funding to continue the important data collection on our sites. As for Swarth Moor, we intend to support the excellent dragonfly volunteers to continue to survey Swarth Moor, and perhaps other peat restoration sites. And if a white-faced darter reintroduction becomes a possibility in within the Yorkshire Peat Partnership area, we know there is the local enthusiasm for dragonflies and the local skillset for doing the baseline survey work.

8.2 SCHOOL ENGAGEMENT

In March 2025, Yorkshire Peat Partnership led a school trip to Swarth Moor for a local school, Bentham Primary. The school group was Key Stage 2, age 7-11, and 22 children took part.

The aim of the day was for local school children to learn about the history, the value and the future protection of Swarth Moor, and to become ‘champions’ of this important and precious peatland habitat.

The day included learning about bogs and peat and explored some of the plants and habitats which this supports. The students were taught about the historical damage which had been done to Swarth Moor as part of peat-cutting, and the work that organisations like YPP were doing to restore peatlands for carbon and for wildlife. Finally, the students learnt about the dragonflies which live on Yorkshire’s peatlands, and how a wet bog is needed for these dragonflies to complete their lifecycles.

The day focused a lot on engaging the senses, exploring the colours and sights and sounds of the peatlands, and encouraged the students to bounce on the bogs and to re-enact the dragonfly lifecycle. Finally, they were encouraged to think about what they wanted for the future of Swarth Moor and create some artwork as a standing stone of this.

Engagement monitoring was done to see what impact the day’s activities might have had on the children’s nature connectedness. The tool used to assess this was the Illustrated Inclusion of Nature in Self (IINS) scale (Kleespies, et al., 2021). This is a simple age-appropriate way of measuring a child’s nature connectedness, by asking the question ‘How connected do you feel to nature?’. Each of the children then puts a mark on one of the options – which show varying overlaps between a circle showing ‘Me’ and a circle showing ‘Nature’ (Figure 8.1a). This question was asked at the beginning of the day whilst standing in the car park, and then the same question on a fresh survey form at the end of the day standing on the bog which they had spent the day exploring and learning about. The school group were asked to not think too much about what everyone else is writing, and to just to go with their instinct when marking their choice. The results of the survey were anonymous.

The results of this survey are shown in Figure 8.1b. If we convert this alphabetical IINS scale (A-G) into a numerical scale (1-7), then we can carry out some statistical analysis. Before the activity, the mean score with standard deviation on the IINS scale for the school group was 4.73 ± 1.76. After the activity, the mean score was 5.55 ± 1.80. There is not a statistically significant difference between the ‘Before’ average IINS score and the ‘After’ average IINS score (p-value of 0.0714, $p>0.05$, unpaired one-tailed t-test), which is partly a result of the small sample size. This means that there is not enough information from this school group survey to say that there is a change in the average nature connectedness INSS score with a high degree of confidence.

However, there is a statistically significant increase in the proportion of students that estimated a high degree of overlap, as defined as the highest scores of 6 or 7 (p-value of

0.0319, p<0.05, two-proportion z-test). This means that we can say with a reasonably high confidence that there is an increase in the proportion of students scoring the highest nature connectedness scores on the IINS scale following the Swarth Moor school trip.

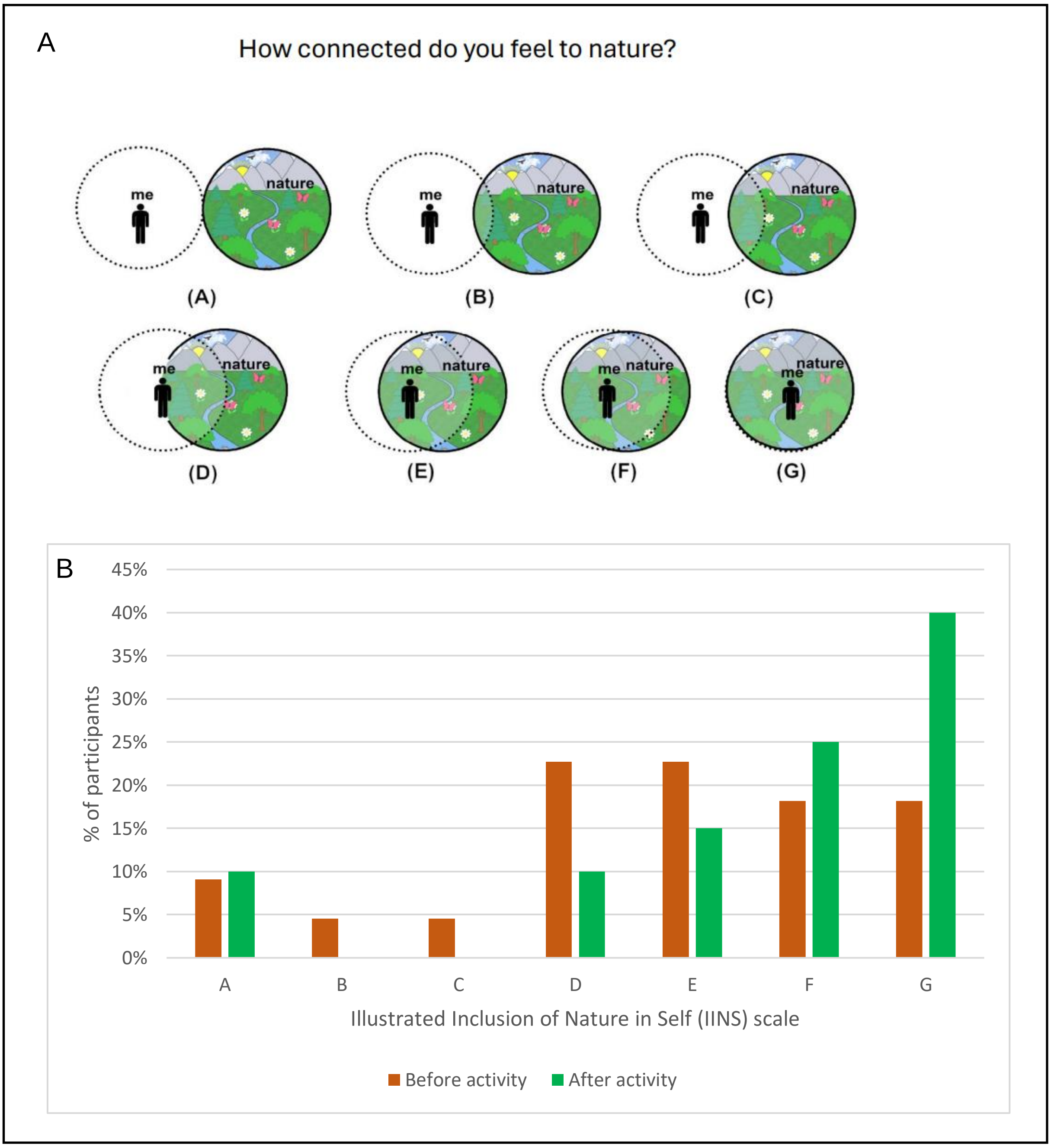

Figure 8.1 – Using the IINS (Illustrated Inclusion of Nature in Self) scale to measure the effect of session focused on peatlands and dragonflies has on nature connection of a primary school group. A) The question sheet used in the survey, images and research originating from Kleespies, et al., 2021. B) The percentage of participants who identified with the choices on the IINS scale before and after the activity i.e. school trip to Swarth Moor.

This tells us that that there is something interesting going on here: that a 3.5 hour school trip to a small local bog resulted in an increase in the proportion of students scoring the highest nature connectedness scores on the IINS scale. The school children were enthusiastic enough to share some feedback at the end of the trip, saying that their favourite parts of the day included: the history of peat bogs and Swarth Moor, bouncing on the bog, holding dragonfly exuviae, and acting as a nymph in the dragonfly lifecycle activity. Using such metrics are important tools for developing school sessions within the scope of the curriculum and which create space for nurturing the next generations' love of nature.

Yorkshire Peat Partnership has begun using the IINS monitoring tool as standard in recent years to measure changes in nature connectedness following different peatland-focused activities, especially with school groups. The data described here is contributing to this larger dataset which will provide us with a better understanding of what activities support nature connectedness the most, and this will allow us to quantify the engagement outcomes of our activities. At a time when nature is in decline in the UK, and our disconnect with nature is cited as being the root cause of this crisis (Richardson, M., 2022), it is important to create opportunities to develop a love of nature in the next generation.

PART 9: CONCLUSION

In this report, we have described the ideal habitat requirements for the white-faced darter *Leucorrhinia dubia* and have detailed the optimal range of each parameter for a population to thrive in the UK. Equipped with this database of habitat requirements, we designed a habitat suitability assessment protocol which could gather the data we needed. From this we developed a new Habitat Suitability Index, for objectively scoring a peatland for L. dubia suitability.

Following the pond creation and peat restoration, the habitat suitability index for the intervention area on Swarth Moor increased from 65 ($\sigma = 22$) pre-works to 82 ($\sigma = 34$) post-works, compared to the known white-faced darter site on Fenn's & Whixall Mosses which scored 96 ($\sigma = 27$), identifying that establishment of *Sphagnum cuspidatum* on the ponds is currently limiting Swarth Moor's scoring. This presents a novel tool which can be used by groups interested in monitoring sites with an existing white-faced darter population, or groups investigating new sites for reintroduction programmes.

In this project, we also presented the results of two models for white-faced darter distribution in Great Britain. Under the future model, the suitability for white-faced darter undergoes extreme climate pressure in the next decades, as annual temperatures rise and precipitation levels shift. This model should be used in conjunction with habitat data; in other words, good lowland raised bog habitat under good management shouldn't be overlooked because it has a poor climate scoring. Nevertheless, these results do serve as a stark warning to continue and increase efforts to preserve this species and its habitat.

One of the most encouraging findings from our Odonata surveys was the range and abundance of dragonflies recorded post-restoration on the severely degraded upland blanket bogs in both the Yorkshire Dales and North York Moors. The style of the interventions appears to impact the recolonisation of dragonflies to a restored peatland. For instance, two similar sites revealed very different results; the most records were found on the site which had formed 10s of large, deep pools behind peat dams over a small area, instead of a larger site with 100s of shallow peat dams which had only two records.

The results of these surveys show that peat restoration plays an important role in restoring habitat for dragonflies and damselflies. In future, we would like to see more peat restoration work monitoring biodiversity outcomes such as dragonfly surveys pre- and post-works.

Although the Species Recovery Programme fund comes to an end in March 2025, Yorkshire Peat Partnership intends to continue the work on the white-faced darter. We are seeking further funding to continue the research towards a white-faced darter reintroduction to suitable site(s) in Yorkshire, and we are collaborating with reintroduction projects in other counties to achieve the joined-up approach which is needed for this species to survive. We are supporting our volunteers to continue monitoring the dragonfly records on Swarth Moor and beyond, and we are working towards measuring biodiversity outcomes such as dragonfly data alongside peat/carbon outcomes in our peat restoration work.

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PART 11: APPENDICES

Appendices are listed below with reference to the corresponding part in the text.

- Appendix 1 – Table S1 Dragons in the Dales supplementary GN
    - For supplementary information detailing the database drawn upon and a list of parameters used in the literature review
- Appendix 2.1 – Habitat Suitability survey raw data 2024 JM
- Appendix 2.2 – Habitat Suitability Survey and Habitat Enhancement Plan JM
- Appendix 3.1 – Swarth Moor Odonata results 2023 JM
- Appendix 3.2 – Swarth Moor Odonata and weather results 2024 JM
- Appendix 3.3 – Fleet Moss Odonata data 2022 KG
- Appendix 3.4 – Fleet Moss Odonata data 2024 AS
- Appendix 3.5 – Bransdale Moor Odonata data JM
- Appendix 3.6 – Rosedale Common Odonata data JM
- Appendix 4 – YPP Technical Specification - Dragonfly Pond Creation AS
- Appendix 5.1 – Habitat Suitability survey raw data 2025 JM
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- Appendix 6.1 – HSI raster for Whixall
- Appendix 6.2 – HSI raster for Swarth pre works
- Appendix 6.3 – HSI raster for Swarth post works
- Appendix 6.4 – HSI raster for Swarth change
- Appendix 6.5 – WhiteFacedDarter_HSI_Analysis.model3
    - This is the QIS model which was used to score the Habitat Suitability Index of different sites
- Appendix 6.6 – Habitat Suitability Assessment protocol and HIS protocol WFD
    - This outlines the full field and UAV parameters to repeat the Habitat Suitability Assessment proposed above, and how to use the Habitat Suitability Index
- Appendix 7.1 Climate suitability GB_present
- Appendix 7.2 Climate suitability Yorkshire_present
- Appendix 7.3 Climate suitability GB_future
- Appendix 7.4 Climate suitability Yorkshire_future
- Appendix 7.5 Climate suitability GB_change
- Appendix 7.6 Climate suitability Yorkshire_change
- Appendix 8: School IINS data and analysis AT

PART 12: REFERENCES

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