Recapture rates and habitat associations of *Leucorrhinia dubia* (White-faced Darter; Vander Linden) on Fenn’s and Whixall Moss, Shropshire, UK

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Abstract

Land-use change and habitat loss are important drivers of biodiversity decline at both global and local scales. To protect species from the impacts of land-use change it is important to understand the population dynamics and habitat associations across these scales. Here we present an investigation into the survival and habitat preferences of *Leucorrhinia dubia* at the local scale at Fenn’s and Whixall Moss, Shropshire, UK. We used mark-release-recapture methods to investigate survival and used sightings of individual dragonflies along with habitat data to investigate habitat preference. We found that survival between capture-visits was very low and that *L. dubia* showed a clear preference for the open moss habitat on this site. In both cases, we found that the detectability, either through sightings or recaptures, was potentially very low and suggest that this should be taken into account in future analyses. We suggest that by encouraging recorders to submit complete lists and to repeat visits to sites detectability could be easily estimated for dragonfly species and incorporating this into analyses would improve estimates for population trends and habitat associations.

Introduction

There has been a marked decline in global biodiversity in the last several decades, a decline which is expected to continue, and this has been largely attributed to changes in land-use activities (Sala, 2000). Land-use activities include agriculture, forestry, creation of urban areas, and use of natural resources (Foley et al., 2005). These activities have a huge impact on environmental characteristics and often cause habitat loss and fragmentation, contributing largely to the decline in global species diversity (Holloway et al., 2003). As such, management and protection of habitats and populations is vital at both local and global scales (Foley *et al.*, 2005; Holloway et al., 2003).
A bias exists in conservation research towards charismatic vertebrates (Di Marco et al., 2017). Although Odonata are charismatic invertebrates they are not immune to this bias (Clausnitzer et al., 2009). In addition much research into Odonata focuses on physiology, evolution and behaviour (Córdoba-Aguilar, 2008) and they have rarely been the focus of conservation research (Clausnitzer et al., 2009). Basic ecological research into demography, survival and habitat use is essential for effective protection of species and habitats. For any taxa this requires detailed ecological and life history data collected in the field. These are often difficult to obtain, particularly on large scales. Integrating large scale data such as presence-only distribution datasets with more detailed local information is a current challenge in conservation ecology (Powney & Isaac, 2015).

Methods to analyse habitat preferences are varied depending on the data available. The current ‘gold standard’ is the use of site occupancy models which take into account detectability (the probability that a species is detected in a site if present) when estimating occupancy (the probability that a species is present in a site) (MacKenzie et al., 2003). Models using this framework help avoid the problem of “imperfect detection”, i.e. failing to spot a species during a survey on a site where it is actually present (MacKenzie et al., 2003). These models require repeated surveys where both detections and non-detections are recorded. However, these data are rarely available. On larger scales a number of methods exist which can use only presence records along with environmental covariates (Elith & Leathwick, 2009). These can tell us about habitat use but are constrained to estimate a measure of the relative importance of habitats rather than the true probability of presence (Elith et al., 2011) and are limited by the environmental data available. At very small scales, such as individual protected areas, detailed data on habitats and landcover can be difficult to obtain because datasets collected on global/continental scales lack the resolution required and bespoke methods of producing these data (e.g. drones) are currently expensive or require intensive fieldwork (e.g. ground-based methods). Datasets such as the UK landcover map (LCM2015), although the resolution is 15m, are too crude for local studies in some areas. Simpler methods which indicate preferred habitat, such as selection indices (Manly et al., 2007), have fewer assumptions and can be revealing even at small scales (Neu et al., 1974).

Investigating survival and movement requires recognition of individuals and methods using mark-release-recapture are well established (McCrea & Morgan, 2014). Such analyses can give information about the age-sex specific survival probabilities of individuals, the use of different sites or habitats and how these
change over time, and the likelihood of encountering individuals again in the future. High quality data of this type can provide accurate estimates of population size. Mark-release-recapture methods have been used on Odonata populations in the past to monitor rare species (Foster & Soluk, 2004; Cordero-Rivera & Stoks, 2008) as well as to study the life history of more abundant species (Bennet & Mill, 1995; Anholt et al., 2001). In particular, Zygopterans have been the focus of several detailed studies on life-history which used mark-release-recapture methods including Bennett & Mill (1995) who studied survival in *Pyrrhosoma nymphula* and both Fincke (1982) and Banks & Thompson (1987) who investigated lifetime reproductive success in *Enallagnma hageni* and *Coenagrion puella* respectively. Since odonates can be individually marked relatively easily, they have also been used as model species for methodological research on the development of mark-release-recapture techniques (Manly & Parr, 1968).

*Leucorrhinia dubia* is a specialist of lowland peatbogs, where it breeds in bog pools containing sphagnum mosses (Smallshire & Swash, 2014). Its life cycle includes a 1-3-year larval period (Smallshire & Swash, 2014). Emergence is weather dependent and typically starts in either May or June. Tenerals are thought to disperse to low scrub following emergence, staying there whilst they mature. Following this, the adults return to breeding pools, with males returning sooner than females so they can hold breeding territories (Smallshire & Swash, 2014). The adult flight period typically ends in either late July or August. *Leucorrhinia dubia* has a scattered distribution and its populations have been declining in Britain over the past several decades. Despite being classified as a species of least concern on the IUCN Red Data List (Clausnitzer et al., 2009), this decline in Britain has resulted in a classification of Endangered on the Odonata Red Data List for Britain (Daguet et al., 2008). The decline is largely attributed to habitat loss and the resulting habitat fragmentation (Daguet et al., 2008). Thus, over 90% of England’s peatbogs have been lost or substantially damaged by the beginning of this century (English Nature, 2002). There are currently only three stable historical populations of *L. dubia* in England, along with two recently reintroduced populations, one in Cumbria and one in Cheshire (Clarke, 2014; Meredith, 2017).

In the current study two methods were used to investigate important ecological characteristics of *L. dubia* on Fenn’s and Whixall moss in Shropshire, UK. Mark-release-recapture was used to investigate survival and movements of adults during the flight period, and a selection index method to investigate habitat use.

**Methods**
Study area

Fenn’s, Whixall and Bettisfield Mosses (FWB Mosses; Fig. 1) are located within Shropshire (52°55′N 2°46′W) and they support a large, long-established population of *L. dubia*. FWB Mosses are a lowland raised bog complex of almost 1000 hectares (Meredith, 2017). Historically, the mosses were used for peat cutting and in the 19th century they were drained to allow larger-scale operations to take place (Meredith, 2017). Eventually, in 1990, the mosses were taken over by English Nature (now Natural England) and long-term restoration began, benefitting a whole host of mossland species, including *L. dubia* (Meredith, 2017). Our study focused on Fenn’s and Whixall Mosses which are both North of the Llangollen canal.

Field methods

The site was surveyed twice per week between 22 May and 6 July 2017. This encompassed the peak flight period of *L. dubia* (Smallshire & Swash, 2014). Two separate breeding pools within FWB Mosses were sampled simultaneously, along with a variety of scrub and other potentially suitable habitat. On each sampling occasion, the full sampling area was searched for any *L. dubia* individuals. Different routes were walked on each occasion to allow different sections within the sampling area to be searched at different times of the day. Sampling sessions lasted between 5-10 hours and were carried out between 10.00 and 16.00 BST, as this is the favoured flight period for adult dragonflies (Smallshire & Beynon, 2010). Sampling days were weather dependent (Chin & Taylor, 2009) and weather conditions were recorded on all sampling days. MRR sampling and recording were carried out at the same time.

**Mark-release-recapture** Mature adults were caught using a net and marked with a unique number on their wing (Fincke, 1982; Banks & Thompson, 1987; Bennet & Mill, 1995; Chin & Taylor, 2009), using an Edding 404 permanent marker pen (Plate 1). The insects were then released at point of capture and any behavioural observations recorded. Not all observed individuals were captured and tenerals were excluded from the mark-release-recapture survey as during this life stage they are fragile and handling may cause wing damage (Allen & Thompson, 2010). Tenerals are easily identified by their pale green colouration, a lack of their full adult colouration and by their shiny wings (Smallshire & Swash, 2014). Insects recaptured on day of marking were not re-counted (Foster & Soluk, 2004). Following initial marking, recapture on successive days was only necessary when relevant information could not be collected from re-sighted individuals (Lettink & Armstrong, 2003).
**Habitat selection index** *Leucorrhinoa dubia* presence was recorded while searching the site during the mark-release-recapture. This included captured individuals as well as those seen on survey routes but not captured. On each occasion the location of the individual was recorded with a hand-held GPS unit (Garmin GPSMAP 64). Additionally, a phase 1 habitat survey (Joint Nature Conservation Committee, 2010) was conducted across the study site to produce a habitat map using 100 x 100 m grid cells. The proportions of five habitat types were recorded in each square: moss (peat moss, rushes and sedges), scrub (low woody vegetation), scrub-moss (peat moss with low woody vegetation), water (open pools) and woodland (mature trees). From this the dominant habitat in each square was calculated. Of these, only water was not used in analyses as adult individuals tended to be sighted over terrestrial habitat.

**Data analysis**

**Mark-release-recapture** Daily survival probability and the probability of recapture were estimated using a continuous-time open mark-release-recapture model, as described in Fouchet *et al.* (2016). Classic mark-release-recapture models require that time is divided into discrete units while Fouchet et al.’s model time can be measured on a continuous scale. This allows robust estimates in the case of lags between capture sessions of varying duration. The analysis was carried out using the *CMRT* package (Santin-Janin & Fouchet, 2015) in R version 3.5.0 (R Core Team, 2018).

**Habitat selection index** Selection indices calculate habitat use as a ratio between habitat where a species is recorded compared to the proportion of each habitat within the study area (Manly *et al.*, 2007). Although relatively simple they can be effective in indicating habitat use (Manly *et al.*, 2007). Selection indices can be sensitive to the scale used in calculating habitat use. However, Neu’s index is relatively robust to changes in scale (Neu *et al.*, 1974) and hence was used in this study. Neu’s index calculates $w_i = \frac{u_i}{\pi_i}$, where $w_i$ is the proportion of squares of each dominant habitat type among all of the squares with *L. dubia* records and $\pi_i$ is the proportion of each dominant habitat type among all of the squares in the study area. Values of the index 1 indicate use of a habitat type in a higher proportion than other habitats available in the study area. Selection index analysis was performed in R version 3.5.0 (R Core Team, 2018) using the *adehabitatHS* package (Calenge, 2006).
Results

**Mark-release-recapture Model**

A total of 13 sampling days were carried out at FWB Mosses from the 22nd May 2017 until the 7th July 2017. During these sampling days, a total of 50 adult White-faced Darters were marked (41 males and 9 females), and a total of 6 recaptures were made. Probability of survival between sampling days was estimated at 0.06 (95% confidence intervals: 0.02-0.17). Probability of recapture on each sampling day was estimated at 0.05 (95% confidence intervals: 0.00-0.11).

**Selection Index**

A further 248 individual *L. dubia* were observed during the fieldwork, all of which were not captured but only observed from a distance (Fig. 2). *L. dubia* show a clear preference (Neu’s index > 1) for ‘moss’ habitats while ‘scrub’, ‘scrub and moss’ and ‘woodland’ appear to be avoided (Neu’s index < 1) (Fig. 3).

**Discussion**

The mark-release-recapture model suggested that both adult survival and recapture rates were low. Although low capture rates might be expected in a large invertebrate population and have been noted before in Odonata (Cordero-Rivera & Stoks, 2008), this was lower than expected. Although male *L. dubia* hold territories they are less tied to these sites than species such as *Libellula quadrimaculata* (Four-spotted Chaser) and so are less predictable in their movements (Merritt et al., 1996). We suggest that future mark-release-recapture approaches for this species, and other similarly cryptic species, need a greater number of capture days and more researchers in the field making captures. This increase in effort is likely to increase the capture rate and increase the accuracy of estimates.

Many more *L. dubia* were seen than were captured and they showed a positive selection for the ‘moss’ habitat as opposed to the other habitats available across the site. The ‘moss’ habitat consists of peat with low heather vegetation and wet flushes and is the habitat most commonly found at pool edges. This is the habitat described in previous research on *L. dubia* (Dolný et al., 2018) and described in
Boudot & Kalkman (2015) as including “peat moss, rushes and sedges”. Locally on this site, *L. dubia* appear to avoid complex vegetation, including scrub and woodland. However, *L. dubia* sites, especially those in Scotland which represents the stronghold for this species in Britain, are often forested (Cham *et al.*, 2014). Breeding pools within these sites are likely to be in open areas but the association with woodland, particularly ancient woodland (Cham *et al.*, 2014), is suggestive of some associations between *L. dubia* and these habitats at larger scales.

The difference between habitats at Fenn’s and Whixall Moss and in the Scottish highlands is potentially due to the availability of suitable bog pools. At Fenn’s and Whixall Moss these are man-made and generally not close to woodland and scrub. In the Scottish highlands these bog-pools are often within a woodland at low altitudes. The difference may also reflect individuals seen in this study where adult males were sighted more often than females or tenerals who might use complex habitat such as woodland more often as cover. Bias towards recaptures of adult males was also noted by Bick and Bick (1961) in their mark-release-recapture study of *Lestes disjunctus australis*. Habitat use across the range of this species in Britain is an area that warrants further research, particularly at the local scale.

*L. dubia* are well camouflaged within their habitats and, as such, there is a good chance of missing individuals because of habitat complexity (i.e. low detectability, Mazerolle *et al.*, 2007). Unfortunately, our field methods did not allow us to estimate detectability in terms of sightings but the low capture probability suggests it is very low. In future we suggest that survey methods are designed so that detectability can be estimated explicitly, in order to get more accurate estimates of occupancy and thus of resource selection. At present we unable to determine whether *L. dubia* are avoiding more complex vegetation or whether individuals are harder to see and therefore record in these habitats.

Data which allows the estimation of detectability can easily be collected with just a few minor changes to currently common survey methods. The majority of these changes are already being requested by the British Dragonfly Society to provide data for the upcoming State of the Nation’s Dragonflies in 2020. We emphasise two of particular importance:

1. Complete lists. Records should be made of all the Odonata species detected on a single visit and thus allow non-detection to be inferred where species are not recorded (Isaac & Pocock, 2015). This requires recorders to note very common species as well as rarities. Unfortunately, there is a tendency in biological recordings to note only the rare or exciting species
(e.g. first record of the year) and this can bias our inferences about population change amongst more common species (Isaac et al., 2014).

2. Repeated site visits. This helps to estimate the detectability of a species (MacKenzie et al., 2003) and consequently obtain unbiased estimates of occupancy, not affected by imperfect detection. We also suggest that, where possible, recorders include some measure of effort in their surveys (e.g. time spent surveying or distance walked). Ideally this would be standardized and included in official protocols such as those already commonly in use for bird surveys.

We present the results in this paper as an indication of what can be done in terms of conservation research in Odonata. Although we have been unable to make firm inferences regarding *L. dubia* survival and habitat preference, this study provides valuable information for the design of future studies. We suggest that research into the conservation ecology of *L. dubia*, along with other Odonata species threatened with declining ranges, declining populations or habitat loss, is essential to the long-term conservation of these species. Methods for such studies can be well informed by current practices used with other taxa. In particular, the analytical advances made in ornithology, research on Lepidoptera and work related to the use of data collected through citizen science provide a fantastic opportunity to advance our knowledge on the conservation ecology of Odonata.

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Plate & Figure Legends

Plate 1: A marked male *Leucorrhinia dubia* at Fenn’s and Whixall Moss in 2017.
Figure 1: Location of the sampling location on Fenn’s, Whixall and Bettisfield mosses showing a) the study area indicated by the black point and b) presence locations of *Leucorrhinia dubia* within the study area.
Figure 2: Number of *Leucorrhinia dubia* of different sex and age classes recorded in Fenn’s and Whixall Moss in May-July 2017.
Figure 3: Neu’s selection index for *Leucorrhinia dubia* records on Fenn’s and Whixall Moss. The red dashed line represents a selection index of 1 (i.e. no selection). If the confidence intervals are above the red line, the habitat is positively selected, while if the confidence intervals stay below the red line, the habitat is negatively selected.
Plate 1
Figure 1