BIOLOGICAL CONSERVATION 127 (2006) 420–428

available at www.sciencedirect.com

SCIENCE DIRECT®

journal homepage: www.elsevier.com/locate/biocon

Epigeic spiders as ecological indicators of conservation value for peat bogs

Alan G. Scott[a,✠], *Geoff S. Oxford*[b], *Paul A. Selden*[a,*]

[a]School of Earth, Atmospheric and Environmental Sciences, The University of Manchester, Manchester M13 9PL, UK
[b]Department of Biology (Area 18), University of York, P.O. Box 373, York YO10 5YW, UK

ARTICLE INFO

Article history:
Received 16 May 2005
Received in revised form
21 August 2005
Accepted 5 September 2005
Available online 14 November 2005

Keywords:
Araneae
Log-abundance
Mires
Naturalness index
Sampling protocol
Species–area relationship
Species quality index

ABSTRACT

Raised and basin bogs are in serious decline throughout the western Palaearctic. There is a need for a monitoring protocol that would signal changes in the habitat and the biota it supports. Spiders (Araneae) are a group of predators containing many bog specialist species, some of which are of Red Data Book status. Twelve-month continuous trapping in 11 basin bogs in Cheshire (western England) established the species present, their phenology, and relative abundance. Data were combined with those from another 21 lowland bogs obtained from the literature and a number of common statistical descriptors calculated. Some of these were of little value, but the number of spider bog indicator species is shown to be a surrogate for the conservation value of the total invertebrate fauna of bogs in the study area. A model short-survey protocol is devised and tested. Using this protocol and suggested stopping rules, it appears that adequate indication of good peatland sites can be assumed when the naturalness index exceeds 0.5, the species quality index is $\geqslant$1.8, and the indicator species–area relationship gives a datum point on or above the trend line derived from the full data set.

1. Introduction

Lowland raised and basin bogs are becoming increasingly rare within a European context, with active raised bogs listed as priority habitats in Annex 1 of the EC Habitats Directive (EC, 1992). In Britain only 6% of an estimated 69,700 ha of original peatland remains intact (Lindsay and Immirzi, 1996), with loss or degradation largely a result of drainage, peat cutting, eutrophication or pollution. In Northern Ireland a similar picture emerges with just 9% of an estimated original 2270 ha of lowland raised bog remaining intact (Cruickshank and Tomlinson, 1988). Lowland raised bogs have been recognised as a priority habitat in the UK Biodiversity Action Plan (2004). These bog habitats are ecologically valuable for a number of reasons: they support a specialised fauna and flora, are an important carbon sink and hold within their depths, in the form of pollen and invertebrate sub-fossils, an environmental history of the local area throughout the Holocene epoch (Maltby, 1997).

There is a perceived need for reliable criteria to rank or otherwise assess the conservation value of threatened habitats and to ensure that the best examples are preserved (e.g., Grünig, 1997 on Swiss mires). In addition, for those sites under active management, measures of the success or otherwise of conservation strategies are essential (e.g., Johnson, 1997). A wide variety of survey methods have been used for these purposes, varying from the purely subjective, through qualitative indices to complex quantitative

* *Corresponding author*: Tel.: +44 2079426077.
E-mail address: paul.selden@manchester.ac.uk (P.A. Selden).
✠ Deceased September 2004.
0006-3207/$ - see front matter
doi:10.1016/j.biocon.2005.09.001

evaluations, and using floral, faunal or abiotic data. An ideal assessment protocol would be sufficiently robust and reproducible to allow year-to-year site monitoring, meaningful comparisons of different sites and grading against some quality standard for the habitat type. It would also need to be light on manpower, inexpensive and not damaging to the habitat.

Past records of the biota of a priority site are often the result of casual recording by volunteers and, although valuable, inevitably embody personal and methodological biases. Other, more systematic, surveys may be based on single site visits, be difficult to replicate and may not detect recent environmental change or inform management policy. Invertebrate surveys are no longer a novelty, but McGeoch (1998, p. 197) considered that 'There are few cases where ecologists can provide decision-makers with tried and tested terrestrial insect indicators as tools for conservation assessment and planning'. Arthropods form a large proportion of the cursorial epigeic fauna of sphagnum bogs, beetles and spiders being the major predatory mesofauna. Spiders have not been much used in site assessments although the ecology of bog species has become a growth area of arachnological research in recent years (e.g., Felton and Judd, 1997; Kupryjanowicz et al., 1998; Relys et al., 2002). Eyre and Woodward (1996) regarded spiders of limited usefulness in the assessment of moorland and woodland situations as a result of year-to-year differences in catches and poorly defined habitat preferences, they also have the disadvantage than they can, in the main, only be identified to species when sexually mature. However, lowland oligotrophic bogs support a highly distinctive invertebrate community (Coulson and Butterfield, 1985) with many specialised species, including spiders. As these habitats have little vertical stratification, most of the spider species are accessible to pitfall trapping, which provides the nearest approximation to quantitative data. Being predators, the larger species may occupy the top trophic level and be expected to integrate the biotic and abiotic influences affecting lower trophic levels. Several bog spider species are considered endangered and, as the subjects of Biodiversity Action Plans (BAPs) in the UK, require monitoring in their own right.

This study assesses the potential of spiders as ecological indicators of peat-bog integrity in western Britain on the basis of data obtained from year-long monitoring and previously published surveys, analysed using a number of statistical descriptors. It also evaluates an efficient survey protocol that can be replicated by different investigators and yields data useful to site managers.

2. Methods

2.1. Study area

The region of Britain considered here is shown in Fig. 1. It comprises the Cheshire plain, north Shropshire and north Staffordshire, parts of north- and mid-Wales, Lancashire, Cumbria and south-west Scotland. One site in West Yorkshire was included. These areas share the high rainfall of an oceanic climate, glacial drift geology and an abundance of ombrotrophic raised, basin and valley bogs.

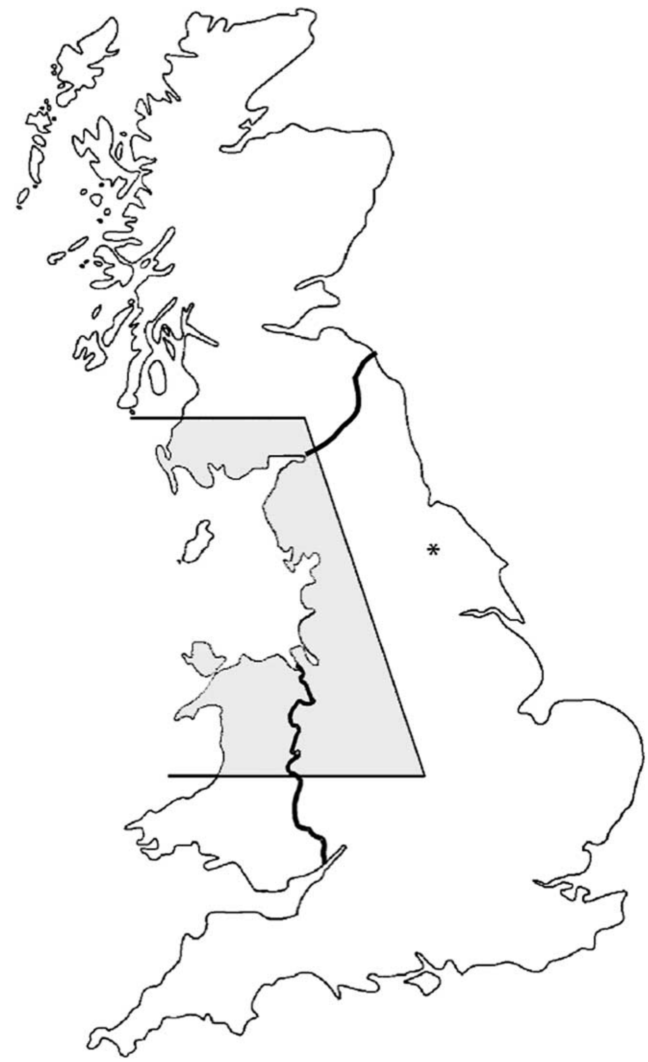

Fig. 1 – The study area. The limits shown on the map (between 52°10′N and 55°20′N, west of the Pennines) are somewhat arbitrary, but are chosen to include major post-glacial peatland sites for which there are important historical biological records. The Welsh and Scottish borders are indicated; * marks the location of the Yorkshire locality outside of the study area.

2.2. Sampling and species identification

During 1996 and 2000, the spider assemblages of 11 basin bogs in Cheshire were surveyed over 12-month periods (Scott, 2001). Data for another 21 bogs in north-west Britain, with trapping methods (⩾2 trapping stations) and sample sizes (⩾50 spp.) comparable with the Cheshire data and with a flora in the M-series of the National Vegetational Classification (Rodwell, 1995), were taken from the literature (Curtis, 1977, 1979; Drake et al., 1989; Duffey, 1963, 1964; Holmes et al., 1991a,b, 1992, 1995a,b,c). Data for the Cheshire basin bogs were obtained by continuous pitfall trapping with 25 traps per site (five traps per station, spaced at 1 m intervals in a line), using 75 mm diameter plastic beakers protected by ceramic tiles supported 2 cm above the rim and containing 30%

ethylene glycol in water as preservative with a small amount of detergent to prevent larger species crawling out. The pitfall catches were collected fortnightly and were supplemented by litter sieving and hand collection from emergent vegetation (*Eriophorum*, *Erica*). *Sphagnum* samples were taken at each site visit and extracted in a Tullgren funnel, but they added little to the species or individual totals. Species identification was based on the keys of Roberts (1985, 1987) with taxonomic revisions according to the check-list of Merrett and Murphy (2000); 302 species were identified (for the full list see Appendix C in Scott, 2001).

Specific bog indicator species, appropriate to western Britain, were identified for some of the statistical comparisons. These were based on a list given in Ratcliffe (1977) with additional species cited by Tretzel (1955), Casemir (1976) and Kupryjanowicz et al. (1998). These species are not necessarily stenotopic for bogs (tyrphobionts) but are unlikely to occur in drier habitats. This list was adjusted for taxonomic revisions since 1977 and the recent extension into the study area of species with previously more southerly distributions.

2.3. Data analysis

A number of measures were used to summarise the data on the arachnofauna of the bog sites and to explore their usefulness as robust indicators of conservation value. We used two measures of diversity (Magurran, 2004). The inverse Simpson index, one of the most meaningful diversity indices available, reflects the evenness of species abundance although it may be unduly influenced by common species. The Berger–Parker index is used as a measure of dominance.

Naturalness in relation to bogs was defined by Ball (1992, p. 44) as 'species believed to be confined to this type of habitat'. For the purposes of the present study, naturalness relates to the spider assemblage only and is the proportion of the total species list thought 'appropriate' to wetland habitats. Sufficient knowledge of the ecology of the chosen group is obviously necessary in order to assign species to one or other category. Indicator species are by definition appropriate, but other species that are regularly encountered and can be shown to complete their lifecycles in the habitat may also be considered appropriate in this context. Species that are normally associated with other habitats, are present as accidental invaders, or cannot be shown to be present at all developmental stages, are classified as inappropriate.

The species quality index (SQI) requires that all species present, including the inappropriate species, be given a numerical score according to their rarity. There are several ways of doing this. Here, we used Red Data Book, Notable, Local and Common designations (Ball, 1992), as indicated in Harvey et al. (2002). Because there are very few high-scoring spider species among the peat-bog fauna, the SQI appears low compared with that derived for other taxa. Therefore, we weighted the top end of the scale more heavily (c.f. Ball, 1992), and scored as follows: Common = 1, Local = 2, Notable B = 4, Notable A = 8, RDB3 = 16, RDB2 = 32 and RDB1 = 64. The status of some recent additions to the British list is not established, so for the purpose of this exercise *Heliophanus dampfi* has been given 32 points and *Gnaphosa nigerrima* 64 points, according to their vice-county occurrences (Harvey et al., 2002). The SQI is expressed as the sum of rarity scores divided by the number of species.

In addition, species–area relationships for indicator species were calculated and log-abundance distributions were investigated for their ability to indicate possible disturbance to the spider communities (Magurran, 2004; Ugland and Gray, 1982).

2.4. Development and testing of an efficient sampling protocol

On the basis of data from the 12-month surveys, a much shorter survey protocol was designed and evaluated at Wybunbury Moss (Ordnance Survey National Grid Reference SJ697503) in 1999 and Holcroft Moss (NGR SJ685935) in 2000. Details of the shorter survey are given below.

3. Results

The cumulative species total over the 32 bogs considered here reached 302, a figure that approaches half of the total spider species known for Britain (645: Merrett and Murphy, 2000). This is a similar proportion of the national fauna to that found by Vilbaste (1981a,b) for a series of bogs in Estonia. Lists of bog indicator and others species considered appropriate to bogs in the study area are given in Tables 1 and 2, respectively. The appropriate species indicated in Table 2 are eurytopic, but are recorded from many peatland sites in the study area and throughout the western Palaearctic.

3.1. Analyses of the 12-month data sets

Diversity indices require reproducible quantitative data, which can be difficult to obtain for invertebrates in heterogeneous habitats. As argued above, the most reproducible technique in the present context, although not without its critics, is the use of continuous pitfall trapping. Calculation of diversity indices was therefore restricted to the pitfall data. The inverse Simpson Diversity index derived from the pitfall data showed a strong negative correlation with the dominance index ($r_{(9)} = -0.95$, $P < 0.001$, Fig. 2) when averaged over a full 12-month period for the 11 Cheshire basin bogs. However, the dominance may vary with the identity of the most abundant species (in the above surveys it was usually *Pirata hygrophilus* Thorell [Lycosidae]) and, as was pointed out by Hurlbert (1971), communities with different species compositions are not intrinsically arrangeable in linear order of diversity. In the case of spiders, the dominance index can change rapidly with the season, particularly during the mating (more active) periods of the abundant species which may produce sharp peaks in numbers trapped (Scott, 2001). The SQI gave values varying between 1.8 and 3.0, and the index of naturalness for the least disturbed sites in this study gave figures in excess of 0.5, i.e., more than half of the species were appropriate to a bog habitat.

A log–log plot of indicator–species numbers against area for the 32 bogs considered here yielded a slope of 0.128 ($P < 0.001$, d.f. = 30, Fig. 3). This is at the low end of the range

Table 1 – Spider indicator species for peat bogs in western Britain

Rugathodes instabilis (Theridiidae)
Robertus arundineti (Theridiidae)
Theonoe minutissima (Theridiidae)
Ceratinella brevipes (Linyphiidae)
Walckenaeria clavicornis (Linyphiidae)
W. nodosa
W. vigilax
Gnathonarium dentatum (Linyphiidae)
Tmeticus affinis (Linyphiidae)
Hypomma bituberculatum (Linyphiidae)
Maso gallicus (Linyphiidae)
Hypselistes jacksoni (Linyphiidae)
Trichopterna thorelli (Linyphiidae)
Silometopus elegans (Linyphiidae)
Satilatlas britteni (Linyphiidae)
Lophomma punctatum (Linyphiidae)
Gongylidiellum murcidum (Linyphiidae)
Notioscopus sarcinatus (Linyphiidae)
Glyphesis cottonae (Linyphiidae)
G. servulus
Erigonella ignobilis (Linyphiidae)
Diplocephalus permixtus (Linyphiidae)
Araeoncus crassiceps (Linyphiidae)
Erigone capra (Linyphiidae)
Semljicola caliginosus (Linyphiidae)
Leptorhoptrum robustum (Linyphiidae)
Halorates distinctus (Linyphiidae)
Drepanotylus uncatus (Linyphiidae)
Hilaira excisa (Linyphiidae)
H. nubigena
H. pervicax
Carorita limnaea (Linyphiidae)
Aphileta misera (Linyphiidae)
Porhomma pygmaeum (Linyphiidae)
Agyneta cauta (Linyphiidae)
Maro minutus (Linyphiidae)
M. lepidus
Centromerus arcanus (Linyphiidae)
C. levitarsis
C. dilutus
Tallusia experta (Linyphiidae)
Sintula corniger (Linyphiidae)
Bathyphantes approximatus (Linyphiidae)
B. setiger
Kaestneria pullata (Linyphiidae)
Taranucnus setosus (Linyphiidae)
Lepthyphantes angulatus (Linyphiidae)
Microlinyphia impigra (Linyphiidae)
Allomengea vidua (Linyphiidae)
Tetragnatha striata (Tetragnathidae)
Trochosa spinipalpis (Lycosidae)
Arctosa leopardus (Lycosidae)
Pirata piraticus (Lycosidae)
P. tenuitarsis
P. hygrophilus
P. uliginosus
P. latitans
P. piscatorius
Dolomedes fimbriatus (Pisauridae)
Argyroneta aquatica (Cybaeidae)
Antistea elegans (Hahniidae)
Hahnia pusilla (Hahniidae)
Agraecina striata (Liocranidae)
Clubiona stagnatilis (Clubionidae)
C. norvegica
C. phragmitis
Gnaphosa nigerrima (Gnaphosidae)
Xysticus ulmi (Thomisidae)
Heliophanus dampfi (Salticidae)
Sitticus caricis (Salticidae)
S. floricola

Families and species arranged according to the check-list of Merrett and Murphy (2000).

Table 2 – Other species thought appropriate for peat bogs in western Britain

Ero cambridgei (Mimetidae)
Euryopis flavomaculatum (Theridiidae)
Theridion pictum (Theridiidae)
Robertus lividus (Theridiidae)
Walckenaeria alticeps (Linyphiidae)
W. atrotibialis
W. nudipalpis
W. kochi
Maso sundevalli (Linyphiidae)
Peponocranium ludicrum (Linyphiidae)
Pocadicnemis pumila (Linyphiidae)
Oedothorax gibbosus (Linyphiidae)
Pelecopsis mengei (Linyphiidae)
P. parallela
Cnephalocotes obscurus (Linyphiidae)
Gongylidiellum vivum (Linyphiidae)
G. latebricola
Meioneta saxatilis (Linyphiidae)
Centromerita concinna (Linyphiidae)
Bathyphantes gracilis (Linyphiidae)
B. parvulus
Lepthyphantes tenuis (Linyphiidae)
L. cristatus
L. mengei
L. ericaeus
Microlinyphia pusilla (Linyphiidae)
Pachygnatha clercki (Tetragnathidae)
P. degeeri
Hypsosinga pygmaea (Araneidae)
Pardosa pullata (Lycosidae)
P. nigriceps
Alopecosa pulverulenta (Lycosidae)
Trochosa terricola (Lycosidae)
Pisaura mirabilis (Pisauridae)
Hahnia montana (Hahniidae)
Dictyna arundinacea (Dictynidae)
Agroeca proxima (Liocranidae)
Phrurolithus festivus (Liocranidae)
Clubiona reclusa (Clubionidae)
C. trivialis
Drassodes cupreus (Gnaphosidae)
Haplodrassus signifer (Gnaphosidae)
Zelotes latreillei (Gnaphosidae)
Micaria pulicaria (Gnaphosidae)
Zora spinimana (Zoridae)
Tibellus maritimus (Philodromidae)
Ozyptila trux (Thomisidae)
Neon reticulatus (Salticidae)

Families and species arranged according to the check-list of Merrett and Murphy (2000).

of slopes for mainland sites (0.1–0.2) collated by Gorman (1979) and Rosenzweig (1995). Most sites that had been given a Grade 1 classification by Ratcliffe (1977) were on or above the trend line (Fig. 3). The only exceptions were a complex and elevated site in Scotland that had a blanket-bog component, and an elevated valley bog in Cumbria. These, though Grade 1, were below the line and had an indicator–species density that differed from the lowland raised and basin bogs. Although there may be marked differences between the spider faunas of lowland ombrotrophic bogs and blanket bogs (Coulson and Butterfield, 1985), and the number of spider families also decreases with altitude, the trend line of Fig. 3 may be a useful guide for the separation of better from poorer lowland sites.

The 11 basin bogs in Cheshire, from which abundance figures restricted to pitfall trapping were available, were subjected to log-abundance plots. For large, species-rich assemblages, species abundances should exhibit a log-normal distribution (Preston, 1948; Magurran, 2004). However, the full bell-shaped distribution is unlikely to be evident from moderate sample sizes, where many species may be represented by just one individual, placing the mode in the first category. Even so a smooth, truncated curve, such as that shown in Fig. 4(a) for Abbots Moss South (NGR SJ594686), suggests a community in equilibrium, whereas the presence of multiple peaks may be the result of habitat disturbance or pollution (Ugland and Gray, 1982). Of the 11 sites analysed here, most showed some irregularities (multiple peaks, plateaux or both), contrasting with that in Fig. 4(a). One such was Abbots Moss North (Shemmy Bog, NGR SJ595689) (Fig. 4(b)), a bog closely adjacent to Abbots Moss South and of similar size (2.8 ha) and number of indicator species. A disturbance of this spider community might be expected because the removal of trees, with associated trampling, had occurred on and around the bog immediately prior to sampling, whereas Abbots Moss South remained undisturbed during this period. Naturalness and SQI were similar for the two bogs, but the inverse Simpson diversity index was higher for Abbots Moss North, perhaps also a result of the disturbance.

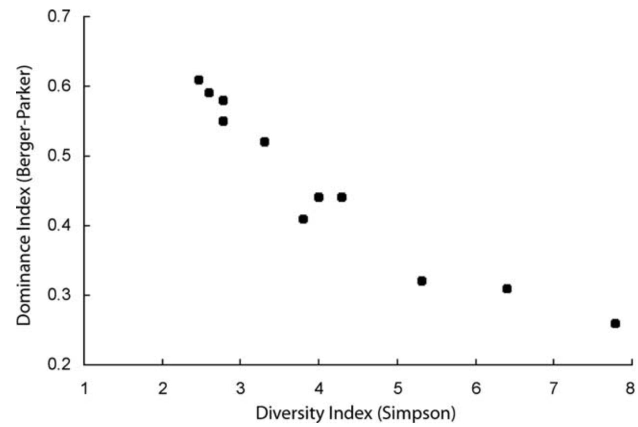

Fig. 2 – The negative correlation between dominance and diversity indices from 12-month pitfall catches of spiders on 11 basin bogs in Cheshire. Pearson's $r_{(9)} = -0.950$, $P < 0.001$.

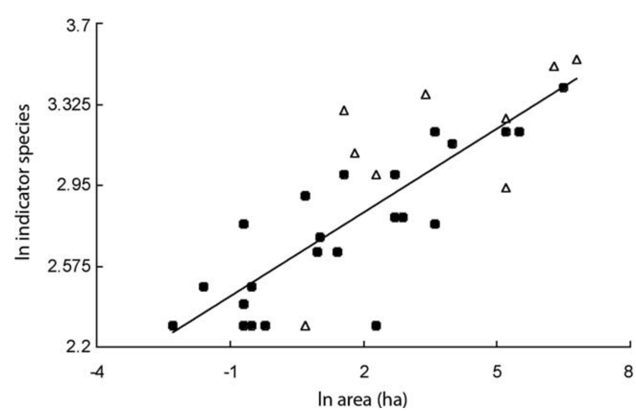

Fig. 3 – Indicator species–area relationship for spiders from 32 bogs in western Britain. The slope of the trend line (z) = 0.128, Pearson's $r_{(30)} = 0.812$, $P < 0.001$. Triangles indicate sites considered Grade 1 by Ratcliffe (1977).

3.2. *Development of an efficient sampling protocol*

For all of the indices tested, but especially those that use presence/absence data, standardisation of sample sizes is required if sites are to be compared and/or monitored over time. A short-duration survey which gave results similar to the 12-month data sets would also be highly desirable, allowing efficient monitoring and a more rapid response when urgent conservation decisions need to be made (McGeoch, 1998). An examination of the phenologies of the 70 indicator species (Scott, 2001; Harvey et al., 2002) suggested that 90% of them might be encountered in a survey restricted to the months of May and June, a period during which the peak numbers of individuals trapped also occurred. However, the data from the 12-month surveys showed that the proportion of the indicator species trapped in the May/June period (from 25 traps) was closer to 75%.

Standardisation of sample size for a short-survey protocol requires a stopping rule (Peterson and Slade, 1998). The log-abundance analysis is best served by a spread of at least 10 abundance octaves, when the dominant species in pitfall catches is represented by between 512 and 1024 individuals. This sample size may be close to revealing the modal category of a log-normal distribution curve while increasing the chance of collecting those indicator species that are shown to have an average activity abundance eight or nine octaves down from the dominant species. In order to provide a sample size adequate for reliable performance of statistical indices on peatland spider data, we suggest that the rule be fixed on the following targets:

(1) The total identifiable individuals captured in pitfalls exceed 1500.
(2) The identifiable individuals of the most abundant species in pitfalls exceed 600.
(3) The total number of identified species (all capture methods) exceeds 60.

From the trapping rate for May/June in the full 12-month surveys we calculate that this stopping rule would require

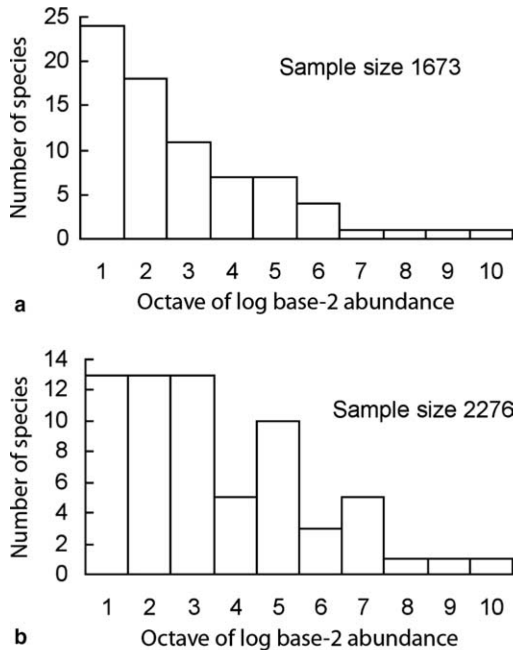

Fig. 4 – Log-abundance plots of spiders from 12-month continuous pitfall captures at Abbots Moss, Cheshire, 1996. (a) South bog with a smooth curve, indicative of near equilibrium of the spider assemblage. (b) North bog showing multiple peaks, suggestive of disturbance due to recent trampling and tree removal.

40 pitfall traps to be set and collection of catch should be weekly, with litter sieving and hand collecting at each site visit similarly enhanced. An additional advantage of the increased number of traps would be a better spread of sub-samples and consequent reduction of errors from the aggregated distribution of species, which had been noted during this study (Scott, 2001) and in that of Relys et al. (2002). Weekly collection might increase the trapping rate (Topping and Luff, 1995) but, even if this were not the case, it would allow early detection and replacement of disturbed traps.

This short-survey protocol was tested at Wybunbury Moss in 1999 and Holcroft Moss in 2000. The former, a basin bog, has probably the most speciose spider fauna in Cheshire and satisfied all three criteria of the stopping rule in six weeks and that for total species by week four. Holcroft Moss, chosen as a challenge for the protocol, is a raised flood-plain bog with a history of draining, burning and grazing, little peat-forming vegetation and an apparently impoverished fauna. This site required six weeks to satisfy the stopping rule for total individuals, but hand collections were continued until week eight to reach the required species total. The SQI was lower for Holcroft Moss (1.3) than Wybunbury Moss (3.0 at week six), reflecting its lack of RDB and other high scoring species. However, an unexpected anomaly appeared in the SQI, on closer examination of the data from Wybunbury Moss. This site has the distinction of being the home of three high-scoring RDB national rarities, which maintain populations such that they are likely to be encountered at small sample sizes. This resulted in the SQI falling with increasing sample size as more low scoring species were added to the list. The three rarities had been collected by the fourth week and with a species total of 67 the SQI was 3.2, at six weeks with a species total of 77 the SQI was 3.0. The survey was extended beyond the stopping point to follow this trend and when the species total reached 84 the SQI had dropped to 2.8. In a larger survey (Felton and Judd, 1997) with a species total of 116 from the *Sphagnum* lawn, the SQI was 2.4. We may assume that this is an exceptional result and the relationship between SQI and sample size will not be as marked at other sites, but this emphasises the need for close matching of sample sizes in monitoring and site comparisons.

Naturalness was higher for Holcroft Moss at 0.66, probably helped by the lack of trees or other tall vegetation on the bog surface. In the case of Wybunbury Moss, the naturalness index was 0.55, very similar to the value of 0.54 calculated from data obtained by Felton and Judd (1997) in a survey undertaken five years earlier in a different season and using different methods.

The choice of season for the short-survey protocol, while designed to maximise the species collected, had an unforeseen artefactual effect on the log-abundance plot. The inclusion of the peak activity period of the dominant and sub-dominant species, enhanced by the higher number of traps, shifted them further up the scale than their nearest rivals, leaving empty octaves (Fig. 5). The continuous plot familiar from the 12-month surveys was not replicated, but the first six octaves may still contain the required information on habitat disturbance. Surprisingly, Holcroft Moss supported 13 bog indicator species, albeit at low densities, compared to the 16 in the short survey at Wybunbury Moss, but when the area of the bog (19 ha) was taken into account Holcroft Moss fell well below the trend line of Fig. 3, while Wybunbury (4.8 ha) was well above.

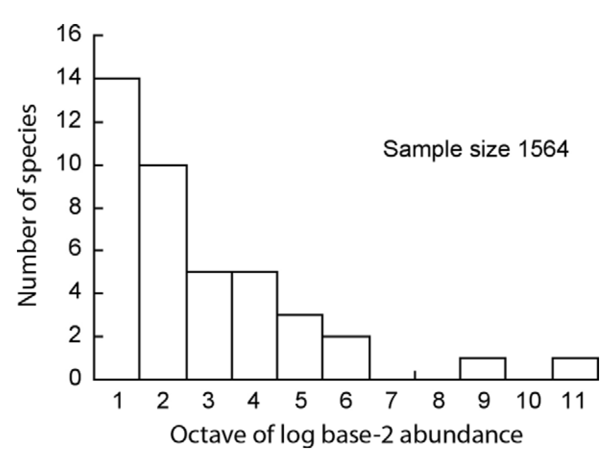

Fig. 5 – Log-abundance of spiders from a short survey at Wybunbury Moss (40 traps for six weeks). The contribution of the dominant (*Pirata hygrophilus*) and sub-dominant (*Pardosa pullata*) species is enhanced by the timing of the survey.

4. Discussion

This study addresses two main issues. First, can indices of, for example, species diversity and naturalness reliably be used to assess the conservation value of lowland raised bogs? Second, if one or more indices can be found, can a standardised survey protocol be developed that captures the required information on site quality more efficiently?

There are obvious shortcomings in the application of the commonly used diversity indices to those invertebrate assemblages in which the capture rate reflects the level of activity of individuals as well as the size of the population and where only sexually mature individuals can be identified to species, as is the case with spiders. It seems unlikely, therefore, that diversity indices would produce a reproducible measure of the equilibrium or quality of the spider assemblage, even when applied to an unstratified habitat, or allow comparisons between sites. There is a further problem of interpretation, as diversity may, in some circumstances, increase after moderate habitat disturbance (Ball, 1992; Petraitis et al., 1989). If such disturbance increases the variety of habitat structure, previously abundant species that depended on the original habitat are stressed and the establishment of new species is facilitated, thus increasing the evenness and the diversity index.

The naturalness index, however, appears to be more stable providing that agreement can be reached on which species are appropriate and which are not. The criteria for the selection of National Nature Reserves in the UK include consideration of the relative abundance of indicator species and paucity of intrusive species (Goode, 1972). Several authors have recently concluded that this relationship is a good indicator when using spider assemblages for peatland site assessment (Kupryjanowicz et al., 1998; Relys et al., 2002). Margules and Usher (1981) found that naturalness was the second most frequently used criterion (after diversity) in a series of nine miscellaneous ecological studies they reviewed. The SQI is also valuable if a points system is agreed for all the species likely to be encountered, and is surely more informative than a survey report concentrating on rarities and ignoring the common species.

The species–area relationship for the bogs considered here yielded a rather shallow slope. One reason for this might be that bogs are habitat islands and larger sizes of bog do not necessarily include different habitats, just more of a single specialised habitat type (the mire expanse) consisting of a lawn of *Sphagnum* and other low-growing acidophilous plants. Increasing habitat variability at increasing scales is a major (but not the only) contributor to species–area effects (Williamson, 1988; Rosenzweig, 1995) and for relatively uniform habitats edge effects will tend to decrease with area. Nevertheless, the derived relationship provides a guide as to whether a specific bog site, on the basis of its area, is enriched or depauparate in indicator species.

For a single invertebrate group to be used as a bio-indicator it is essential that it can be shown to reflect the quality of the total biota of the habitat (McGeoch, 1998). It is more likely to do this if it is mobile and in a higher trophic level. An opportunity to test this relationship for the spider fauna of bogs was provided by the data from the Welsh Peatland Invertebrate Survey (Holmes et al., 1991a,b, 1992, 1995a,b,c), which contain species lists from 13 invertebrate orders, collected concurrently at 130 sites during the months of June to October. Forty of the more northerly sites were chosen to include a range of mire types, sizes, vegetational classifications, altitude and sample sizes. These ranged from blanket bog, through raised, basin and valley mires to poor fen and calcareous flushes. The number of spider indicator species was compared with the log of the total RDB and Notable species in the other taxa. The result is shown in Fig. 6. The significant positive correlation suggests that the spider indicator species are an acceptable surrogate for the conservation value of the total invertebrate mesofauna.

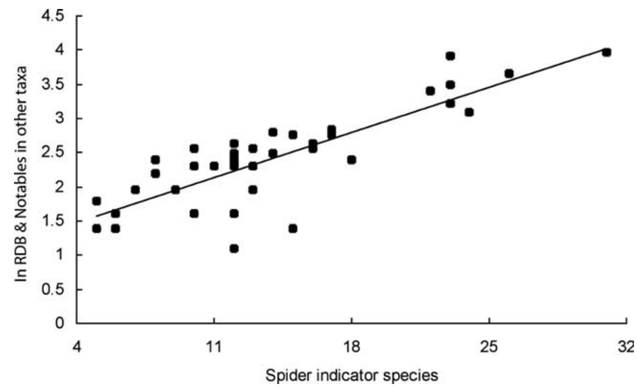

Fig. 6 – Plot of ln RDB and notable species from other invertebrate taxa against spider indicator species collected in the same sampling period from 40 Welsh mires. Some of the data points are coincident. Pearson's $r_{(38)} = 0.828$, $P < 0.001$.

Using the short-survey protocol and stopping rules suggested here, it appears that adequate indication of a good peatland site could be assumed when the naturalness index exceeded 0.5, the SQI was $\geqslant 1.8$, and the indicator species–area relationship gave a datum point on or above the trend line shown on Fig. 3. These three criteria have the advantage that, apart from the quantitative requirements of the stopping rule, only presence/absence data are necessary and a mix of collecting methods is allowed. If quantitative data are available for all the pitfall-collected species, the log-abundance plot may give an indication of whether the community is near equilibrium or disturbed.

The usefulness of this protocol for year-to-year monitoring remains to be tested. Relys et al. (2002) stated that there was no turnover in the abundant spider species in consecutive years if the pitfall-trap positions remained constant, although there were marked annual differences in individual abundances. Changes in the abundance of the dominant species, usually a lycosid, is to be expected, because each year's adult population is generated from overwintering immatures that are subject to a varying mortality from both biotic and abiotic factors. However, it is possible that the shape of the log-abundance plot will be retained in consecutive years even if some of the constituent species change in each octave, a dynamic equilibrium noted by Ugland and Gray (1982) in a marine benthic community. The numerical relationships derived here also need to be tested outside the present study area.

There seems to be sufficient basis for accepting spiders as ecological indicators for peat bogs as they satisfy most of the criteria suggested by McGeoch (1998). Although simple observations of the invasion of the bog surface by grasses and trees can give an indication of deterioration of the biotope by lowering of the water table and/or eutrophication, spider surveys may signal other changes that stress the mesofauna and its constituent valued species. The presence of adequate numbers of indicator species at low density may identify those degraded and cut-over bogs that would respond to restoration attempts, e.g., at Holcroft Moss (see also Oxford and Scott, 2003).

Acknowledgements

We are grateful to the Countryside Council for Wales for allowing the use of the data from the Welsh Peatland Invertebrate Survey, and to the Cheshire Wildlife Trust and English Nature for permits to trap spiders on their reserves. Comments from two anonymous referees improved the clarity of the paper.

REFERENCES

Ball, S.G., 1992. The importance of the invertebrate fauna of Thorne and Hatfield Moors: an exercise in site assessment. Thorne & Hatfield Moors Papers 3, 34–65.

Casemir, H., 1976. Beitrag zur Hochmoor-Spinnenfauna des Hohen Venns (Hautes Fagnes) Zwischen Nordeifel und Ardennen. Decheniana (Bonn) 129, 38–72.

Coulson, J.C., Butterfield, J.E.L., 1985. The invertebrate communities of peat and upland grasslands in the north of England and some conservation implications. Biological Conservation 34, 197–225.

Cruickshank, M.M., Tomlinson, R.W., 1988. The Northern Ireland Peatland Survey. Report to Countryside and Wildlife Branch, Department of the Environment (NI), Belfast.

Curtis, D.J., 1977. Lowland Bogs Spider Survey. Nature Conservancy Council, Peterborough.

Curtis, D.J., 1979. Spiders in Lowland Bogs in South West Scotland. Nature Conservancy Council, Peterborough.

Drake, C.M., Godfrey, A., Sanderson, A.C., 1989. A survey of the invertebrates of five lowland bogs in Cumbria. England Field Unit Project 80. English Nature, Peterborough.

Duffey, E., 1963. Ecological studies on the spider fauna of the Malham Tarn area. Field Studies 1 (5), 65–87.

Duffey, E., 1964. Spiders in Shropshire. Bulletin of the British Spider Study Group 21, 1–4.

EC, 1992. European Community Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Official Journal of the European Communities, No L 206/7, Brussels.

Eyre, M.D., Woodward, J., 1996. Spiders in environmental surveillance and site assessment. Environmental Monitoring, Surveillance and Conservation using Invertebrates. In: Eyre, M.D. (Ed.), EMS Publications, Newcastle upon Tyne, pp. 26–28.

Felton, C., Judd, S., 1997. *Carorita limnaea* (Araneae: Linyphiidae) and other Araneae at Wybunbury Moss, Cheshire – a unique refuge for two relict species of spider in Britain. Bulletin of the British Arachnological Society 10, 298–302.

Goode, D.A., 1972. Criteria for selection of peatland nature reserves in Britain. In: Proceedings of the 4th International Peat Congress, vol. I. Otaniemi, Finland, pp. 167–177.

Gorman, M.L., 1979. Island Ecology. Chapman and Hall, Chichester.

Grünig, A., 1997. Survey and monitoring of mires in Switzerland. In: Parkyn, L., Stoneman, R.E., Ingram, H.A.P. (Eds.), Conserving Peatlands. CAB International, Wallingford, pp. 217–227.

Harvey, P.R., Nellist, D.R., Telfer, M.G., 2002. Provisional Atlas of British Spiders (Arachnida, Araneae), vols. 1 and 2. Biological Records Centre, Huntingdon.

Holmes, P.R., Boyce, D.C., Reed, D.K., 1991a. The Welsh Peatland Invertebrate Survey: Montgomery. Countryside Council for Wales, Bangor.

Holmes, P.R., Boyce, D.C., Reed, D.K., 1991b. The Welsh Peatland Invertebrate Survey: Ceredigion. Countryside Council for Wales, Bangor.

Holmes, P.R., Boyce, D.C., Reed, D.K., 1992. The Welsh Peatland Invertebrate Survey: Merioneth. Countryside Council for Wales, Bangor.

Holmes, P.R., Boyce, D.C., Reed, D.K., 1995a. The Welsh Peatland Invertebrate Survey: Anglesey. Countryside Council for Wales, Bangor.

Holmes, P.R., Boyce, D.C., Reed, D.K., 1995b. The Welsh Peatland Invertebrate Survey: Denbigh. Countryside Council for Wales, Bangor.

Holmes, P.R., Boyce, D.C., Reed, D.K., 1995c. The Welsh Peatland Invertebrate Survey: Caernarvon. Countryside Council for Wales, Bangor.

Hurlbert, S.H., 1971. The nonconcept of species diversity: a critique and alternative parameters. Ecology 52, 577–586.

Johnson, B.R., 1997. Monitoring peatland rehabilitation. In: Parkyn, L., Stoneman, R.E., Ingram, H.A.P. (Eds.), Conserving Peatlands. CAB International, Wallingford, pp. 323–331.

Kupryjanowicz, J., Hajdamowicz, I., Stankiewicz, A., Staręga, W., 1998. Spiders of some raised peat bogs in Poland. In: Selden, P.A. (Ed.), Proceedings of the 17th European Colloquium of Arachnology, Edinburgh 1997. British Arachnological Society, Burnham Beeches, Bucks, pp. 267–272.

Lindsay, R.A., Immirzi, C.P., 1996. An Inventory of Lowland Raised Bogs in Great Britain. Scottish Natural Heritage Research, Survey and Monitoring Report, No 78. SNH, Edinburgh.

Magurran, A.E., 2004. Measuring Biological Diversity. Blackwell, Oxford.

Maltby, E., 1997. Peatlands: the science case for conservation and sound management. In: Parkyn, L., Stoneman, R.E., Ingram, H.A.P. (Eds.), Conserving Peatlands. CAB International, Wallingford, pp. 121–131.

Margules, C., Usher, M.B., 1981. Criteria used in assessing wildlife conservation potential: a review. Biological Conservation 21, 79–109.

McGeoch, M.A., 1998. The selection, testing and application of terrestrial insects as bioindicators. Biological Reviews 73, 181–201.

Merrett, P., Murphy, J.A., 2000. A revised check-list of British spiders. Bulletin of the British Arachnological Society 11, 345–358.

Oxford, G.S., Scott, A.G., 2003. The spider fauna of Askham Bog, York, and the assessment of conservation value. Naturalist 128, 157–170.

Peterson, A.T., Slade, N.A., 1998. Extrapolating inventory results into biodiversity estimates and the importance of stopping rules. Diversity and Distributions 4, 95–105.

Petraitis, P.S., Latham, R.E., Niesenbaum, R.A., 1989. The maintenance of species diversity by disturbance. Quarterly Review of Biology 64, 393–418.

Preston, F.W., 1948. The commonness and rarity of species. Ecology 29, 254–283.
Ratcliffe, D.A., 1977. A Nature Conservation Review, vol. 1. Cambridge University Press, Cambridge.
Relys, V., Koponen, S., Dapkus, D., 2002. Annual differences and species turnover in peat bog spider communities. Journal of Arachnology 30, 416–424.
Roberts, M.J., 1985. The Spiders of Great Britain and Ireland, vol. 1. Harley Books, Colchester.
Roberts, M.J., 1987. The Spiders of Great Britain and Ireland, vol. 2. Harley Books, Colchester.
Rodwell, J.S. (Ed.), 1995. British Plant Communities. Swamps and Tall-herb Fens, vol. 4. Cambridge University Press, Cambridge.
Rosenzweig, M.L., 1995. Species Diversity in Space and Time. Cambridge University Press, Cambridge.
Scott, A.G., 2001. The role of spiders (Araneae) as indicators of the biodiversity and conservation value of peatlands in North-West England and adjacent areas. PhD thesis, University of Manchester.
Topping, C.J., Luff, M.L., 1995. Three factors affecting the pitfall catch of linyphiid spiders. Bulletin of the British Arachnological Society 10, 35–38.
Tretzel, E., 1955. Intragenerische Isolation und Interspezifische Konkurrenz bei Spinnen. Zeitschrift fuer Morphologie und Oekologie der Tiere 44, 43–162.
Ugland, K.I., Gray, J.S., 1982. Lognormal distributions and the concept of community equilibrium. Oikos 39, 171–178.
UK Biodiversity Action Plan, 2004. Available from: <http://www.ukbap.org.uk/UKPlans.aspx?ID=20>.
Vilbaste, A., 1981a. The spider fauna of Estonian mires. Eesti NSV Teaduste Akadeemia Toimetised (Bioloogia) 29, 313–327.
Vilbaste, A., 1981b. The spider fauna of Estonian mires. Eesti NSV Teaduste Akadeemia Toimetised (Bioloogia) 30, 7–16.
Williamson, M.H., 1988. Relationship of species number to area, distance and other variables. In: Myers, A.A., Giller, P.S. (Eds.), Analytical Biogeography. Chapman and Hall, London, pp. 91–115.